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THE RELATIONSHIP BETWEEN ALTERNATIVE PROJECT APPROACHES, INTEGRATION, AND PERFORMANCE

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1996, 133 pages

ABSTRACT

This work compares the performance of traditional construction projects with alternative approaches. It verifies significant advantages for partnered, design-build, and combination projects. Next, a method is developed for measuring "degree of interaction" (DOI) to approximate project integration. DOI is shown to directly impact project performance, and can be used to predict future project performance.

Of 209 completed military construction projects, partnered projects averaged the least schedule growth, design-build projects the lowest cost growth and design deficiencies, and combination projects the fewest modifications. Traditional projects had the worst average schedule growth, modifications, and design deficiencies.

DOI scores were calculated for 38 of the 209 projects. The alternative projects have significantly higher average DOI scores than traditional projects.

Scatter plots comparing DOI and project performance show a clear relationship between the two. As DOI scores rise, project performance quickly improves and becomes more consistent. Beyond a certain DOI score (approximately 0.4), performance levels off. Achieving this score takes only a modest increase in interaction. Performance is significantly better for projects with DOI scores above 0.4. Interaction occurring early in the project also has a positive impact on performance.

Finally, future project performance can be predicted based on DOI scores. The probability of improved average performance for projects with DOI>0.4 is very high. Future projects with a DOI score over 0.4, should average significantly less cost growth, schedule growth, fewer modifications, and design deficiencies, over comparable projects with DOI<0.4.

THE RELATIONSHIP BETWEEN ALTERNATIVE PROJECT APPROACHES, INTEGRATION, AND PERFORMANCE

BY

JAMES BRYANT POCOCK

B.S., University of Michigan, 1981
M.S., Pennsylvania State University, 1988

THESIS

Submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy in Civil Engineering
in the Graduate College of the
University of Illinois at Urbana-Champaign, 1996

Urbana, Illinois

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ABSTRACT

This work compares the performance of traditional design-bid-build projects with alternative approaches. It verifies that partnered, design-build, and combination projects offer significant advantages in cost growth, schedule growth, modifications, and design deficiencies.

Going a step further, a method is developed for measuring an individual project's "degree of interaction" (DOI) as an approximation of project integration. This method is used to show that DOI has a direct impact on project performance. Finally, DOI score is used to predict future project performance.

In comparing 209 completed military construction projects, partnered projects had the least average schedule growth, design-build projects had the least average cost growth and design deficiencies, and combination projects averaged the fewest modifications. Traditional projects had the worst average schedule growth, modifications, and design deficiencies. The significance of these differences is confirmed with *t*-tests.

Degree of interaction scores were calculated for 38 projects from this group of 209, including some of each category. The alternative projects have significantly higher average DOI scores than traditional projects.

A series of scatter plots comparing DOI and project performance shows a clear relationship between the two. As DOI scores rise, project performance quickly improves and becomes more consistent. Regression analysis shows a modest but significant correlation between DOI and project performance, including user satisfaction. Beyond a certain DOI score (approximately 0.4), performance tends to level off. Achieving this score takes only a modest increase in interaction. Threshold analysis separates the projects into those with DOI scores above and below 0.4. Performance is significantly better for projects with higher DOI in all areas except design deficiencies. Interaction

occurring early in the project is also shown to have a positive impact on project performance.

Finally, these results are combined with statistical analysis to predict the performance of future projects based on their DOI scores. The probability of improved average performance on future projects with DOI>0.4 ranges from 80% to 99% depending on the performance indicator. A hypothetical project with a $5 million budget, scheduled to last 365 days, and a DOI score over 0.4, should save $119,500 in cost growth, 71 days in schedule growth, 21 fewer modifications, and 7 fewer design deficiencies, over a comparable project with DOI<0.4.

DEDICATION

This work is dedicated to my family, in particular my wife Anne, who have always supported and encouraged me.

"Trust in the Lord with all your heart and lean not on your own understanding; in all your ways acknowledge him, and he will make your paths straight."

Proverbs 3:5-6

"Serve wholeheartedly, as if you were serving the Lord, not men"

Ephesians 6:7

"For he was looking forward to the city with foundations, whose architect and builder is God."

Hebrews 11:10

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CHAPTER I

INTRODUCTION

A. Background

1. The Need for Improvement in the US Construction Industry

The design and construction industry in the United States has suffered many setbacks and embarrassments in the last 20 years. These include declining productivity, huge cost overruns, increased disputes and litigation, and major construction failures, some with great loss of life. These have all contributed to a general perception of lower quality in today's constructed project.

A major landmark in bringing these problems into focus was the Business Roundtable's Construction Industry Cost Effectiveness Project. The Summary Report, "More Construction for the Money," pointed to a number of these failures. It noted the Commerce Department had reported a 20% decline in construction productivity from 1972 to 1979 (BR, 1983). The project study team attributed more than half the time wasted during construction to "management practices." The Roundtable blamed the construction industry's sluggishness in adopting modern management systems for long delays in schedules and big cost overruns that have plagued construction (BR, 1983). This series of 23 separate reports was aimed at owners, contractors, architects, engineers, academics, and others in the construction industry. The Business Roundtable hoped to catalyze basic changes across the industry including education, contractual relationships, construction methods, union practices, and management techniques. Their aim was to "promote quality, efficiency, productivity, and cost-effectiveness in the industry."

In 1984, the American Society of Civil Engineers (ASCE) sponsored a workshop for construction industry leaders. They were concerned about "the increasing number of

project failures, disappointments, accidents, and other problems that resulted in considerable cost overruns, excessive litigation, injury, and even death." Out of this workshop grew an effort to write a new advisory manual on "Quality in the Constructed Project" which describes "a desirable process for project delivery from conception through design, construction, and operations start-up" to "enhance quality" (ASCE, 1990).

Despite this attention and effort there is plenty of room for improvement. A recent study of critical success factors in 16 construction projects found quality control to be the most common deficiency, and product information (design documents and coordination among the disciplines) was a problem on both good and poor projects (Sanvido et al, 1992). The vice-president of one of the top 100 U.S. construction firms recently said they operate at about 40 or 50% efficiency, and they are competitive because the rest of the industry does too (Anonymous, 1994).

Owners from other industries, who have transformed their firms through down-sizing, reorganization, and total quality management programs say the design and construction industry lags behind. Less than 50% of Associated General Contractors members are using or planning to use quality teams. Of the 6,300 U.S. firms that have earned the European Union's ISO-9000 quality standard, only about 20 are design or construction firms. Only one firm in the construction industry, a material supplier, has ever won the Malcom Baldridge National Quality Award (Schriener et al, 1995).

2. The Origin of Construction Problems

Many of the Business Roundtable's recommendations and much of the research since then have targeted different aspects of construction in trying to improve the industry. Journals and trade magazines emphasize improving construction productivity, construction scheduling, construction safety, construction technology, and construction quality.

Yet the greatest opportunity for enhancing a project's overall quality occurs before construction begins (ASCE, 1990). Most project parameters are determined during the conceptual planning phase. Therefore, the greatest potential for impact from construction expertise is *before* major design decisions are finalized. Construction ideas can contribute to the design then, rather than competing with it. There is also a great opportunity for significant cost and time savings (BR, 1982). In my master's thesis I studied four public-sector construction projects in detail and concluded that problems in design and the design/construction interface have a greater impact on overall project quality than the type of quality control system used (Pocock, 1988).

A recent study of nine fast-track industrial construction projects identified the direct costs associated with rework (including redesign), repair, and replacement. The researchers found that design deviations averaged 78% of the total number of deviations, 79% of the total deviation costs, and 9.5% of the total project cost. Construction deviations average 16% of the total number of deviations, 17% of the total deviation costs, and only 2.5% of the total project costs (Burati, Farrington, & Ledbetter, 1992). A study by the University of Maryland of over 5,000 buildings found that 43% of building failures (involving litigation) were attributable to design (Golish, 1994).

Efforts to improve project quality during construction can only achieve so much without parallel efforts for the planning and design phases and design/construction integration. Many different approaches to improving design/construction integration have been proposed and used in recent years. Among these are partnering, design-build, concurrent engineering, and constructability.

B. Problem Statement

This thesis compares the performance of traditional projects to those using alternative delivery approaches, including partnering, design-build, constructability, and combinations thereof. It then defines and measures "degree of interaction" to show its impact on project performance.

1. Fragmentation of the Project Delivery Process

Many years ago an architect or engineer could rightly be called a "master builder." The master builder designed virtually every aspect of a project, understood how it was built, and directly oversaw its construction. The project delivery process has become much more fragmented with the passage of time. The design and construction phases have been separated by traditional contracts, organizational structure, specialization, and a retreat from legal responsibility.

Traditional design-bid-build contracting keeps designers and builders from interacting. Most engineers and architects have limited construction experience, and do not understand how to design for efficient construction (BR, 1983). Designers tend to emphasize minimizing design costs. They could benefit from contractor input, but contractors are not usually involved in a project until bidding. They work from completed drawings and specifications without having any input to their contents (BR, 1982). Contractors have little interaction with the designers. Their attention is focused on the job site and on minimizing construction costs (CII, 1993).

Both private and public owners separate design and construction into different functions. Projects are often "handed off" from the design organization to the construction organization with little interaction. This creates a deep knowledge gap because the designers are not experts on construction, and the builders have not been

involved in the design (Pocock, 1988). Such separations exist at both the industry and project levels. Separating financial planning, architectural design, and engineering from construction causes missed opportunities for saving time and money (BR, 1983).

These divisions have become so institutionalized that people from different organizations have lost some of their respect for, and ability to work cooperatively with one another. Anyone who has worked in design or construction is aware of the negative attitudes engineers, architects, and contractors can have for one another. These attitudes become part of the culture of many organizations. and contribute to the poor communication that is the root of the problem.

Today architects and engineers rely on many consultants (structural, mechanical, electrical, etc.) and have backed away from their traditional responsibilities during construction. Contractors rely on a long list of subcontractors and may not even perform any work with their own forces. This division of responsibility creates significant communications gaps between individuals and organizations working on the same project.

With the increase in the number of parties and gaps in responsibilities, litigation increases. In response to this increase across the industry, all players are attempting to limit their legal responsibility. Contracts are written attempting to insulate parties from lawsuits, but they contribute to the atmosphere of segregation. For example, an architect visiting a construction site who notices an unsafe condition may decide not to report it for fear of assuming general responsibility for jobsite safety. As one editor says, "Architects always have envisioned themselves as master builders. But these days, they are reluctant to assume the authority and risk that goes along with that role" (ENR, 1994).

Despite the fragmentation, owners, designers, and builders somehow manage to come together and deliver successful projects most of the time. As one A/E consultant comments, "in reviewing past successes, the good projects seem to have come about when

each participant lost the fear of the other team members and communicated openly and honestly" (Ball, 1993).

2. The Traditional Project Delivery Process

A traditional project goes through separate design, bidding, and construction phases. The owner hires an architect or engineering firm (A/E) to design the project, based on its qualifications. The designer works as the owner's agent, expected to represent the owner's interests. When the design is complete, the project is advertised for competitive bids. Interested contractors bid on complete plans and specifications. The project is awarded to the low bidder, and the contractor begins construction.

The owner has separate contracts with both the A/E and the contractor. In this traditional process the A/E and contractor have very limited interaction. The contractor is not exposed to the project until the design is complete. The contractor has limited opportunities during bidding and after contract award to make suggestions or ask questions. The possibility of reducing his or her own cost is the contractor's only motivation for proposing changes to the design. Unfortunately, designers do not understand the impacts of their design decisions on construction as well as builders (Heery, Thomsen, and Wright, 1993). The bulk of the A/E and contractor's interaction consists of the A/E clarifying technical questions for the contractor, and approving the contractor's requests for partial payments based on work completed.

This contractual arrangement does not encourage good communication between the A/E and contractor, and often leads to an adversarial relationship between them. This in turn causes serious problems because the traditional design-bid-build process assumes the A/E has produced error-free contract documents, which is virtually impossible.

For example, if the contractor finds what appears to be an error or omission in the drawings he or she must bring it to the attention of the architect for direction on how to

proceed. When the architect decides, the contractor typically says it constitutes a change requiring an increase in the contract cost. The contractor has contracted to complete the project for a fixed price and is extremely sensitive to anything that could threaten his or her slim profit margin. The architect, on the other hand, wants to protect his or her reputation with the owner for the sake of future work and is extremely reluctant to admit a mistake. As a result, claims, disputes, and law suits are common. Owners are often caught in the middle without the expertise to discern who may be responsible for a particular problem.

This design-bid-build scenario, using firm fixed price contracts, has been the most common form of project delivery in the public sector. This is especially true among federal agencies because federal acquisition regulations require competitive bids and award to the low bidder, except in special circumstances (Schroer, 1993).

Value engineering, or value analysis, is sometimes included in the traditional construction process. It is defined as:

> ***the systematic effort directed at analyzing the functional requirement of systems, equipment, facilities, procedures, and supplies for the purpose of achieving the essential function at the lowest total cost, consistent with meeting needed performance, reliability, quality, maintainability, aesthetics, safety and fire resistance*** (ASCE, 1991)

Value engineering is not included below as one of the approaches compared with the traditional process for three reasons. First, the primary goal of value engineering is to save money, not to increase project integration. Second, as it is currently used in public construction, value engineering is limited to one aspect of the design review process. For example, any military construction project over $10 million requires a value engineering analysis. A value engineering consultant typically reviews a partial or final design to identify cost saving changes that still satisfy the project requirements. The consultant has usually not been part of the design team. In the private sector, and overseas, a more comprehensive form of value engineering is practiced. But in our public construction

value engineering tends to be reactionary rather than participatory. Finally, value engineering's best features are included in a comprehensive constructability program (see 7. below).

3. Alternative Approaches to Improving Design/Construction Integration

Planning, design, construction, start-up, operation and maintenance are all phases in what should be a continuous process. Instead, owners, designers, and contractors have chopped it into separate pieces. They each have their own project objectives and criteria for measuring success. Some criteria which are common to all include; on time, on budget, profit or fee goals satisfied, and no legal claims. A recent study of 16 construction projects used these to identify four critical factors of successful projects: (1) A cohesive team to plan, design, and construct the project, (2) contracts that encourage team behavior and allocate risk fairly, (3) experience in all project phases, and (4) designability, constructability, and operability information from and available to the project team (Sanvido et al, 1992).

Today owners are demanding better quality, more innovative and cost-effective designs, less risk, fewer delays, less litigation, and faster project delivery. These pressures are causing owners, architects, engineers, and contractors to consider alternatives to the traditional project delivery process (ASCE, 1992). A variety of approaches exist and are being used to satisfy these demands through improved integration. Among the most promising are partnering, design-build, concurrent engineering, and constructability. Each of these approaches has the potential to improve project integration in a different way.

a. Partnering

In the late 1980's, the Army Corps of Engineers began using the concept of "partnering" to replace the adversarial relationship so common in traditional projects with

an atmosphere of cooperation. The Corps defined partnering as, "the creation of an Owner-Contractor relationship that promotes the achievements of mutually beneficial goals" (Hightower, 1993). Partnering is a non-contractual attempt to change the nature of the relationships between owners, contractors, designers, and others involved in a construction project. The objective is to build them into a team. The Construction Industry Institute (CII) has defined **partnering** as:

> ***a long-term commitment between two or more organizations for the purpose of achieving specific business objectives by maximizing the effectiveness of each participant's resources. This requires changing traditional relationships to a shared culture without regard to organizational boundaries. The relationship is based upon trust, dedication to common goals, and an understanding of each others individual expectations and values. Expected benefits include improved efficiency and cost effectiveness, increased opportunity for innovation, and the continuous improvement of quality products and services*** (CII, 1991).

Partnering is not a contract, and should not be confused with a formal "partnership". Instead, it is a voluntary relationship within the context of a construction contract.

Despite the emphasis on a long-term relationship, public sector agencies have used partnering successfully one project at a time. A case study in which a government agency implemented a "project partnering" arrangement with the contractor for a $70 million heavy civil project proved successful despite their short-term relationship (CII, 1991).

b. Design-Build

Design-Build (also called design-construct) is a contractual arrangement in which one firm or joint-venture, is responsible to the owner for both design and construction. It affords opportunities for time and cost savings because of allowing phased construction and management efficiencies (Clough, 1986). The owner issues a "request for proposals" based on definitive or performance criteria. The request for proposals normally includes some preliminary design work performed by owner's

engineering staff or a separate A/E firm. Interested design-build contractors submit their solution for both the design and construction which best meets the owner's requirements. Rather than selecting the low bidder, owners usually evaluate proposals in terms of satisfying criteria, contractor qualifications, and design quality, as well as cost. This sets the contract price at an early design level. With design-build, the owner does not have to resolve conflicts between the designer and builder. The design-build contractor has total responsibility for providing a facility that meets all the owner's criteria.

Because the designer and builder are both part of the same organization, design-build sets up conditions for good cooperation and interaction between them. In particular, it gives the builder the opportunity for input during the entire design process. Ideally, a representative of the constructor is part of the design team.

c. Constructability

One method of project integration originally suggested by the Business Roundtable is constructability. The Construction Industry Institute (CII) formed a Constructability Task Force in 1986 to study this approach. They defined **constructability** as **"the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives"** (CII, 1986). Constructability is not just another checklist of items to consider during the design review. By then, the opportunity for major innovation has already passed, while pride, cost, and time considerations make changing completed designs difficult. The emphasis is on bringing construction knowledge to bear in the earliest project phases, before major design decisions have been made. The construction expert should be a full-fledged member of the design team.

Constructability is not intended to be used instead of other integration approaches. It is completely compatible with Total Quality Management, design-build, partnering, and

concurrent engineering. Although it is a separate approach, it can be combined with any of these approaches.

d. Concurrent Engineering

This is a technological approach to project integration. Engineers at The University of Illinois have been doing basic and applied research in this field. They propose Concurrent engineering as a means of improving product (or project) development practice. "The idea is to simultaneously satisfy the functionality, reliability, produceability [constructability], and marketability concerns, to reduce the product development time (i.e., lead-time) and cost, and to achieve higher product quality and value" (Lu, 1992). They envision designers, consultants, builders, and end-users simultaneously working with a computer model of the project to see the impacts of their ideas in real time. Researchers at the Army's Construction Engineering Research Laboratories (CERL), also working on concurrent engineering, are developing and testing prototype software (Golish, 1994).

This is an exciting vision, but even if it is realized, there is no guarantee that today's design and construction industry would use such a tool. The researchers recognize that concurrent engineering requires a cooperative team approach:

> *It calls for technological, organizational, and even cultural changes in our enterprise and society. Although cultural and organizational issues are very critical to the success of concurrent engineering, the research at (Illinois) has mainly focused on providing* ***technological*** *solutions to the problem. In searching for concurrent engineering solutions, we fully realize that cultural and organizational issues have major impacts on the development of technological solutions which, in turn, can result in cultural and organizational changes* (Lu, 1992).

Some organizational and cultural changes must occur throughout the industry before it will be ready for concurrent engineering. Other researchers in this area, Dr. Paul Teicholz and Dr. Martin Fischer of Stanford, say that unless a project team works in a

cooperative environment, integration will not occur regardless of the technology (Teicholz and Fischer, 1994). Design-build, partnering, and constructability are beginning to make the organizational and cultural changes while awaiting the development of usable concurrent engineering technology. This work will not consider concurrent engineering any further since it can not yet be studied in actual projects.

C. Objectives of the Research

As discussed in the next chapter, proponents of these alternative approaches claim that they lead to more successful projects. But do they really? How have they measured success? Do these alternative approaches really increase integration? And is there a correlation between increased integration and project success?

This research compares the relative success of construction projects using several approaches to improve the integration of design and construction. The methodology provides a systematic approach for measuring project success. Specifically, traditionally managed construction projects are compared to projects using design-build, partnering, and combinations of these alternative approaches. The intent is to verify whether these methods do in fact impact project success, and if so, by how much. This thesis also provides a method for measuring a project's "degree of interaction" as a representation of integration. I compare the average degree of interaction of each project category to see how the traditional and alternative projects differ in this respect. The research also explores the correlation between project success and the degree of interaction. Finally, the results will allow public owners to make decisions based upon predicted project success.

D. Thesis Organization

Chapter I begins by describing some of the major problems facing the US construction industry. These include frequent large cost overruns, delays, disputes, and lapses in safety that contribute to a general perception of marginal quality in the industry. The point is made that many, if not most, construction problems have their origins in design. The problem statement points to the artificial separation between design and construction project phases as a major cause of these problems. It describes the traditional design-bid-build process for a typical project. It also defines several approaches to improving design/construction integration including partnering, design/build, concurrent engineering, and constructability. Chapter II examines the literature on partnering, design-build, constructability, and measuring project performance. It concludes by stating how this research makes a unique contribution beyond what has been done to date. Chapter III examines how each of the alternative approaches has been used in the public sector, including some ongoing projects. Chapter IV explains the methodology for this work. It is based on case studies of traditionally managed projects and projects using each of the approaches to project integration. The methodology explains how project success is measured and how case studies are compared. Military construction projects are used as the source of case study projects. Chapter V presents the results and analysis of this work using tables, charts, and statistical analysis. Chapter VI concludes this research with a summary, conclusions, and recommendations for decision makers and for future research.

CHAPTER II

LITERATURE SURVEY

A. Introduction

This chapter begins by reviewing research on integration itself. After considering several possible alternatives to the traditional construction process, value engineering and concurrent engineering have been eliminated from further consideration. Partnering, design-build, and constructability remain. This chapter goes on to examines the literature available on each of these alternative approaches to project delivery. Each section includes a look at the topic in the public sector. The section on partnering also includes a discussion of research into partnering during design. The section on constructability considers barriers to implementing constructability programs. Next comes a survey of how other researchers have attempted to measure project performance. Finally, the summary points to the needs for additional research.

B. Integration

Researchers have been examining alternatives to the traditional approach as opportunities to improve integration, especially since the Business Roundtable's landmark series of reports in 1982. Nam and Tatum (1992) use the term *integration* to mean "integration between design and construction". They have described four major means to increase construction integration: contractual, organizational, information, and non-contractual. In her doctoral dissertation, Fergusson carefully examined research on integration spanning the last 15 years (Fergusson, 1993). She has constructed a comprehensive framework of integration consisting of three dimensions; 1) Vertical -

inter-function, 2) Horizontal - interdisciplinary, and 3) Longitudinal - across time (see Figure 2.1). She has also classified integration into technical (hardware and software) and organizational (humanware) coordinating mechanisms.

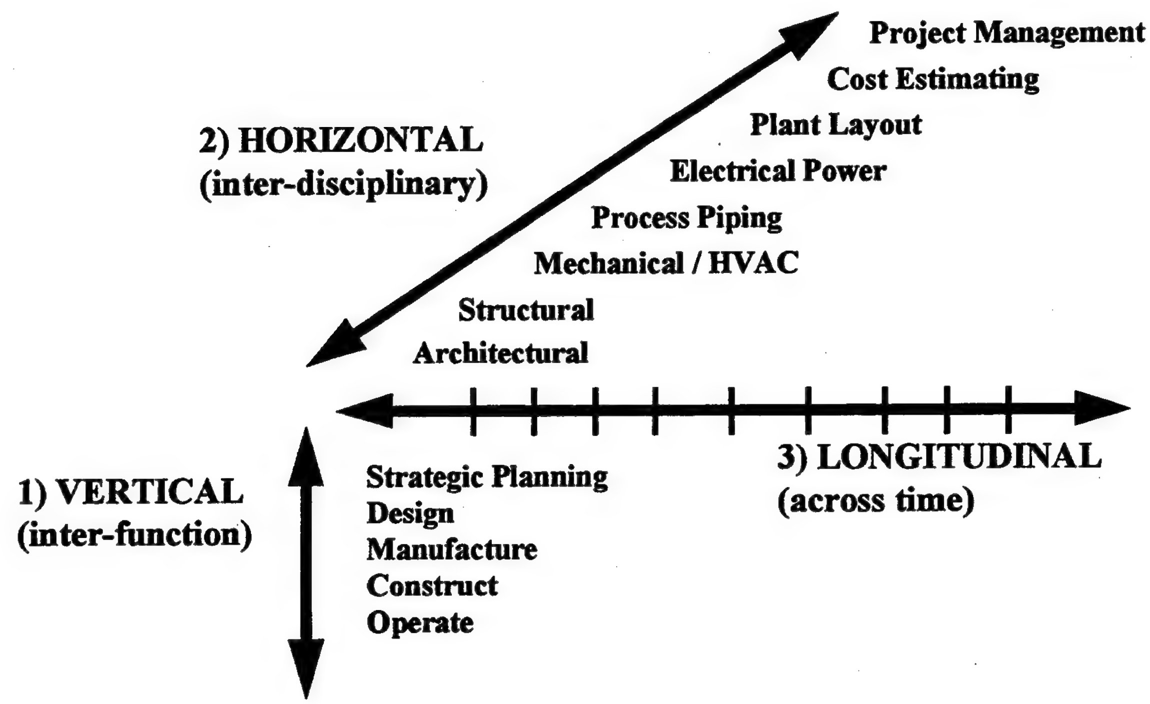

Figure 2.1 Three Dimensions of Integration in Facility Development (adapted from Fergusson (1993) and Thomas (1992))

Cohenca-Zall et al (1994) use the term "degree of involvement" to describe the roles of various parties in construction planning and emphasize the importance of meetings as a major means of planning during construction. This is not to be confused with "degree of interaction" as used in this work. Walker (1995) has demonstrated four factors that affect construction time performance; 1) construction management effectiveness, 2) client relationships with the construction manager and design team, 3) the design team's

communication with the construction manager and client, and 4) project scope and complexity.

Integration in the Public Sector

Public sector construction represents a significant portion of the total industry. In 1994, private and public construction in the United States totaled $285 billion. In 1996, the Defense Department alone will spend $10.6 billion on planning, design, and construction (SAME, 1995). Other federal agencies with large construction programs include the GSA, VA, Postal Service, NASA, EPA, and the Department of Energy. Public sector construction is further multiplied when state and local government projects are included.

Because public construction has traditionally required competitive bidding based on a completed design, opportunities for interaction between designers and builders have been limited. Now, state and federal agencies, hard-pressed by manpower and budget cuts, have begun to take a more serious look at new ways of acquiring quality facilities. Many of these changes are improving project integration. For example, in 1988 the Corps of Engineers made a major organizational change by adding the Project Management Division to provide project continuity between the Engineering and Construction Divisions (Schroer, 1994). At approximately the same time the Air Force removed the separation between management of design and construction, without adding a new management layer. Instead of design managers and construction managers, there is now a single manager responsible for the project "from cradle to grave." As we shall see in this chapter, federal agencies have often pioneered or refined approaches such as partnering and design-build, contributing to their acceptance and use in the private sector.

C. Partnering

According to a representative of one large U.S. construction firm, the essential elements of a successful partnering relationship include:

- commitment to partnering by top management
- a trusting relationship between all parties
- a partnering agreement with specific common goals
- timely resolution of disputes at the lowest level (Choquette, 1993).

There are no legal or regulatory barriers to the open communications embodied in partnering, just human nature (Ball, 1983). Either an owner or contractor can initiate a partnering relationship. Most partnering agreements are between owners and contractors, although some are being used during the design phase between owners and designers, then extended into the construction phase. Partnering can also begin before a contract is awarded if the owner sends a letter to the chief executive officer of each prospective bidder saying that partnering will be used on the project. The partnering process is then explained in detail at the prebid meeting (Tarricone, 1992).

The process begins in earnest when the contract is awarded. The rapport between owner and contractor must first be cultivated at the executive level. On a recent large-scale project the owner's project executive personally called the contractor and welcomed him to the team, "He told me it was the first time an owner ever called him to say that" (Tarricone, 1992).

The executives from each organization plan an initial partnering session that typically lasts two or three days. All members of the project management group attend, including the executives. Their participation is critical for several reasons; it gives the process credibility, it demonstrates their commitment to the process, and the executives have the authority to enable partnering to work.

The partnering session is typically run by a neutral facilitator, for example a management consultant (Demoret et al, 1993). The group receives training in topics such as personal integrity, problem solving, and team building (Roll, 1991). The participants also examine and compare their goals for the upcoming project. For example, on a recent large project the owners listed their project objectives as; quality work, no disputes/claims, on-time delivery, done right the first time, and within budget. The contractor independently arrived at these goals; quality product (pride), no litigation, on schedule, no rework, and within estimate (reasonable profit) (Woodrich, 1993). Although their motivation may be different, the partnering session helps the group members realize that their goals are complementary, if not identical. In other words, when schedule, cost, quality, and disputes goals are met, everyone wins.

The final product of the partnering session is a Partnering Agreement or Charter, signed by all the parties, including the executives. The agreement spells out the goals of the partnering relationship and procedures for processing disputes. For example, the partnering charter for a current construction project at the University of Illinois is signed by the general contractor, architect, subcontractors, suppliers, and university representatives. It emphasizes overall project goals, open communications, performance objectives, and specific procedures for resolving disputes quickly, and at the lowest possible level (Anonymous, 1994b).

The initial partnering session goes a long way toward building a working group that thinks of themselves as a real team. For many participants it may be the first time anyone asks them what their project goals are. With the exception of specific dispute resolution procedures, most partnering agreements are full of general goals that don't have contractual teeth. However, the time spent working together on the agreement becomes a model for the relationship on the project itself. The agreement provides the necessary unifying sense of direction.

A partnering relationship can be compared to a good marriage; it requires trust, good communications, and commitment from both parties to be successful (CII, 1991). In the marriage analogy the initial partnering session is the honeymoon, everyone usually comes out of it feeling good. In the execution process the partnering agreement is put into practice. To those who weren't a part of the initial partnering session, an atmosphere of trust, open communication, and teamwork on a construction project may be a bit of a shock. It requires a cultural change from a defensive posture and "us versus them" mentality. As one project executive admits, some "old cultural attitudes" still need adjusting (Tarricone, 1992). Again, executive leadership is vital in convincing everyone that the partnering agreement is not just another poster on the bulletin board of the jobsite trailer.

The real test of the partnering relationship is whether it lives up to the procedures for resolving disputes spelled out in the agreement. To prevent a scenario as described above in traditional projects, the agreement usually gives step by step procedures for resolving the dispute as quickly and fairly as possible.

For example, the partnering charter from the campus project mentioned above includes four steps. First, the dispute is discussed at the level where it originated and the parties involved are encouraged to use trust and teamwork in resolving it. The second step hopes to prevent litigation by reminding those involved to treat each other with respect and as partners. If steps one and two do not succeed, the third step is to resolve the conflict at the next level of supervision on-site within 72 hours. Finally, if nothing else works, the dispute is resolved by the project executives from each organization (Anonymous, 1994b).

The emphasis is on resolving the dispute quickly, putting it in the past, and getting on with the project. Putting the emphasis on solving problems at the lowest level gives people more authority to make decisions on their own. "Initially many staff personnel

were reluctant to assume this new responsibility, but as the project progressed they grew to really like it" (Demoret et al, 1993). According to one project executive, "Inaction is not an option ... team members cannot choose to not make a decision" (Tarricone, 1992).

If the project management group can consistently make these procedures work they will significantly reduce claims, which helps keep the project on schedule and within budget. But they will also demonstrate to everyone involved that partnering is for real. This will strengthen the atmosphere of trust and cooperation that is the goal of partnering, and the group will be on its way to success.

Once organized and successfully launched, a partnering relationship does not continue on automatic pilot. A number of factors will tend to weaken the relationship if it is not maintained. On any large construction project some things will undoubtedly go wrong. Every problem is an opportunity for individuals to slip back into the familiar way of doing business, especially if they are angry about something. Another factor is the likely turnover of some personnel during the life of the project. New people, unfamiliar with partnering, may disrupt the cooperative atmosphere that has been so carefully cultivated.

Once again executive leadership is required to monitor and maintain the partnering relationship. According to one project executive, his job is to be a "champion, a fanatic" (Tarricone, 1992). For this reason owner and contractor executives will typically schedule follow-up partnering sessions at intervals throughout the project.

The follow-up partnering sessions are a group well-being function and serve two main purposes. First, the project executives use them as a forum to jointly evaluate the project and the partnering relationship itself. This gives project management group members an opportunity to raise problems or ask the group for input on a specific issue. The group considers whether they have been living up to the partnering agreement. The second purpose is to train new group members on partnering and their roles in the

process. The project executives use the follow-up partnering sessions to further imbed the partnering mentality into the group's expected behavior, formal procedures, and written documents. In short, partnering becomes the new group culture.

Although much of the support for partnering has been based on anecdotal evidence, a recent study of 280 construction projects attempts to show a clear difference in the success of partnered projects. The author classified the projects as adversarial, guarded adversarial, informal partners, and project partners. Through questionnaires, the researcher asked project managers and engineers to rate recently completed projects in terms of meeting schedule, controlling cost, technical performance, satisfying customer needs, avoiding litigation, and overall performance. Although based on individual perceptions, the results show that partnered projects had the highest scores for every success criteria. The study also compared projects awarded on a low-bid basis with those that were not and found no significant difference in success between them (Larson, 1995).

1. Partnering in the Public Sector

Partnering has been used so frequently by some firms and organizations (e.g. the Army Corps of Engineers) in recent years that it has gradually become part of the organizational culture. Since March, 1993, it has been the official policy of the Corps of Engineers to "develop, promote and practice partnering on all construction contracts, and to universally apply the concept to all other relationships" (Williams, 1993). The Department of Veteran's Affairs (VA) has incorporated partnering provisions into all its solicitations to bidders since 1992 (Lawson and Lyons, 1995). The use of public-sector partnering, pioneered by the VA and Corps, is spreading rapidly. Other public owners such as the Federal Highway Administration, Arizona Department of Transportation (DOT), Caltrans, and Washington State DOT are now using partnering (Tarricone, 1992).

With the Army Corps of Engineers, as in the VA, partnering is voluntary, and the Corps includes an offer to partner in its contract solicitations to successful bidders. The Corps' system of partnering includes the following steps; internal preparation, secure top management support, hold a partnering session immediately after contract award, write a partnering charter, follow-up meetings during the project, and celebrating success (Schroer, 1993).

There have been many reports of partnering success. For example, the Corps' Medical Facilities office recently compared two 1 million square feet projects, one using partnering. After one year of construction, the non-partnered project had around 3,000 pieces of correspondence between the government and contractor, with over 1,000 requests for information. The partnered project had only 300 pieces of correspondence and 92 requests for information (Allred, 1993).

The authors of a case study of the $226 million Large Rocket Test Facility project at the Arnold Engineering and Development Center in Tennessee portray it as a partnering success story. The Air Force was the owner, the Army Corps of Engineers was the contract administrator, Ebasco/Newberg was the joint-venture contractor, and Parsons/DMJM was the A/E. The partnering team achieved nearly $3 million in value engineering cost savings, excellent safety results (lost-time incident rate of 0.39 vs. national average of 6.2), "no significant quality problems", and expects to finish four months ahead of schedule. The partnering arrangement, which includes all major participants, began with the pre-construction workshop and includes a "partnering charter" which all participants signed. They continuously referred to the partnering charter whenever a problem arose during the course of the project (Demoret, et al, 1993).

Another author, Major Jeffrey W. Hills, has also taken a look at the Corps' use of partnering. He compares data from recently completed partnered and non-partnered projects awarded in the Kansas City District since 1988. The non-partnered projects

averaged 12% cost growth, and 26% time growth. In contrast, the partnered projects averaged 6% cost growth, and 12% time growth. Partnered projects also had fewer contract modifications. Major Hills stressed that successful partnering depends on a written policy, early implementation, and senior management involvement (Hills, 1995).

A more comprehensive study considered both the extent of partnering across the Corps as well as the performance of partnered projects. The study found that all 37 Corps districts had initiated some form of partnering, most with contractors, and a few with other government agencies. None of the districts had yet established a partnering agreement for a project's design phase. The study also compared all 15 partnered projects completed to date with 28 similar but traditionally-managed projects. Average performance was better for partnered projects in the categories of cost change, change order cost, claims cost, value engineering savings, and duration change. Both Corps project engineers and construction contractors made positive comments about their partnering experiences (Weston and Gibson, 1993).

A similar study compares 39 partnered with 100 non-partnered Navy projects. All of the Navy's Engineering Field Divisions were using partnering to some extent. Partnered projects in this study averaged fewer claims, more frequent value engineering savings, and less duration change than traditional projects. Cost change and change order cost were not significantly different. The partnered projects also had less variance than the traditional projects in schedule duration, cost change, and value engineering savings. The vast majority of Navy personnel had positive comments about their partnering experiences (Schmader, 1994).

2. Partnering During Design

With this record for partnering during construction, it was only a matter of time before partnering was applied to design. The Corps of Engineers has begun using

partnering on A/E design contracts, adding the contractor to the partnering team after contract award (Schroer, 1993). The VA has done the same thing. For example, on a $211 million medical center renovation project, the VA conducted a facilitated partnering session with the using agency and A/E during initial project planning. Other members of the design and construction team will join the partnering effort as they become involved (Lawson and Lyons, 1995).

In May 1993, the Federal Construction Council's Consulting Committee on Architecture and Architectural Engineering held a symposium on using partnering during design. Eight papers were presented by representatives from the Corps of Engineers, construction contractors, architects, design consultants, and other practitioners, claiming a variety of benefits for design partnering (FCC, 1993b).

Jerome J. Sincoff, of the architectural firm Hellmuth, Obata and Kassabaum, Inc., wrote on behalf of the American Institute of Architects, emphasizing partnering from the beginning and continuing through the project process. It helps build continuity and shared responsibility with teammates (Sincoff, 1993). Ideally, all teammates should be invested in the goals of the project from the start. One author advocates "fully integrated life-cycle partnering", with the contractor involved during the design phase. This would allow the designer to incorporate improvements suggested by the construction contractor, while the contractor gains ownership of the design, further uniting the project team (Kitchens, 1993).

However, in the public sector, the contractor can join the team at the start of construction with a pause to review the project goals and educate the new member. If builders can participate in the design process, their inputs on constructability, cost, schedule, and local conditions make the design more reliable. This collaboration during the design phases yields the most benefit with the least cost in time, money, and frustration (Sincoff, 1993).

Rex M. Ball, an A/E consultant with HTB Inc., notes that design partnering is similar to the "design charette" process that architects have used for many years. In a charette, the design team works together informally in an isolated setting, perhaps at the project site. Everyone works quickly and closely to define owner/user needs and what is expected of the A/E. This exercise gets the team past individual desires to a group concept of the project (Ball, 1993).

Mr. Ball stresses design partnering as the best way to be sure all parties understand the project's "program". The program is a scope of work the owner and A/E develop describing project criteria and goals in detail. Mr. Ball maintains that misunderstandings of the program by project team members is where most serious problems begin (Ball, 1993).

Whereas partnering during construction is focused on implementing a solution, a partnering team in design is creating that solution. There are many more unknowns during the design phases. The team's work consists of gathering information, making decisions, and getting approvals (Allred, 1993).

The parties are also diverse, including; the owner/maintainer, the user/operator, the A/E, consultants, and the constructor. All have a direct interest in the project and differing goals (Allred, 1993). The A/E wants an aesthetically-pleasing, up to date facility that satisfies the owner's program. The contractor wants to control construction costs and schedule. The owner/maintainer wants a low-maintenance, durable, and flexible facility. The owner/user wants all of their needs satisfied in a new facility they can occupy on time. There is a strong potential for conflict during this stage (Becker et al, 1993). Partnering can focus the parties on the main project objectives to create a solution that all will accept and support.

In a case study of a design partnered research building project, Becker et al describe some of the procedures the team used. All of the partnering team's discussions

were documented as mutually agreed decisions, identifying the party responsible for taking actions. Each team member had the opportunity to bring up issues during weekly meetings. The users signed off on 15 and 30% design submittals to build commitment to decisions. The team decided to build a full-scale laboratory mockup to work out design coordination and maintenance problems, to allow researchers to see the lab, and to allow bidders to study what they were to build (Becker et al, 1993).

Mr. Fred Kitchens, of the U.S. Army Corps of Engineers, writes of three large-scale projects in the Savannah District which were partnered during design. He believes partnering has improved working relationships, reduced the number of changes, and improved project quality. For example, on one of the three projects (a $26 million soldier support institute) design partnering helped reduce design time from the expected 24 months to 11 months, and reduce construction time from 24 months to 17 months (Kitchens, 1993).

During design, architecture usually sets the pace, with other disciplines responding to the limits imposed by the architectural design. Design partnering improves coordination. The other disciplines are encouraged to make inputs earlier in the process, bringing up potential problems when they are easier to solve (Allred, 1993).

Partnering is not only being applied to facility design and construction processes. Many federal agencies, especially the Corps, are doing "strategic" partnering with their major customers. They use the same partnering process to learn what their customers are unhappy about. Some problems, once understood, are relatively easy to solve, resulting in improved trust. This form of partnering allows each party to understand some of the constraints that limit other organizations, which leads to more understanding (Kitchens, 1993).

D. Design-Build

Design-build offers a number of potential benefits to owners. First, it makes one organization responsible for the entire design and construction process. Any design errors or omissions are internal problems for the design-build contractor. This also tends to lower the number of change orders. Direct interaction between designers and builders fosters innovation. Design-build can reduce the total project delivery time by allowing this collaboration, and because some construction can begin before all design is complete. Faster project delivery can contribute to lower total project costs (ASCE, 1992). Owner organizations that are downsizing and reducing their in-house engineering staffs are helping drive an increase in design-build. Between 1988 and 1992, design-build work in the U.S. went from $25 billion to $80 billion (McManamy, 1994).

Owners considering design-build also have a number of concerns to address. The A/E is no longer the owner's agent, but has a direct financial interest in the construction cost. The design-build A/E may be less responsive to changes in the owner's needs because there is already a commitment to a total project cost. A contractor-dominated design team may emphasize low first-cost solutions over low life-cycle cost solutions. The owner no longer has an independent A/E to inspect the construction (ASCE, 1992).

The Business Roundtable reported in 1982 that design-build organizations typically have "average integration" because the contractor's staff are usually involved in only "part-time" constructability input before groundbreaking (BR, 1982). This points to an important distinction among firms calling themselves design-build organizations. The design-build contractor can actually be one of four types: the A/E as a prime contractor (general contractor as subcontractor), the builder as prime contractor (A/E as subcontractor), a joint venture of the A/E and builder, or a design-build organization with

in-house design and construction expertise (ASCE, 1992). In some cases, traditional contractors hire an A/E firm to design a single project but are not involved in the design process. This is in contrast to firms which have their own design and construction experts that work closely together during all project phases. The latter can be expected to have much greater project integration (Speicher, 1994).

There is no single type of project most suited for design-build, however it has proven especially useful on projects of a repetitive nature, such as multi-story office buildings or hotels (ASCE, 1992). Design-build has been successfully applied to a wide range of project types in different sectors of the construction industry. Typical building projects include multi-family housing, office, and institutional. Power projects have included cogeneration, fossil-fuel, and hydroelectric. Design-build has also been used for industrial and highway projects (ASCE, 1992). Design-build projects can now be found in almost every market sector of the industry, including hotels, shopping centers, hospitals, and museums (McManamy, 1994).

Regardless of the project type, the owner's project staff must understand and define the user's project goals. This in-house staff must also understand the design-build process. It is up to the owner to provide comprehensive scope of work information that includes; detailed space and equipment requirements, site surveys, soil borings, outline specifications, a budget, and schedule requirements (ASCE, 1992).

A major issue in design-build is the method of selecting the design-build entity. ASCE has pointed to a conflict between the "selection by qualification" approach used for design professionals and the "low bid" approach traditionally used to award construction contracts. While there is no standard practice for design-build, owners often prequalify a limited number of design-build teams based on their qualifications, then use cost among other criteria for final selection (ASCE, 1992).

ASCE has also considered whether design-build is applicable to "traditional" civil engineering projects such as highways or flood control projects. ASCE's Task Committee on design-build believes these projects are appropriate for design-build if they are given careful attention by owning agencies and design-build teams (ASCE, 1992).

The Task Committee also addressed the concern that design-build may result in lower quality of the final product. Their consensus is that design-build selection criteria weighted more toward qualifications than cost will ensure final project quality (ASCE, 1992).

Trade journals have described the strong growth of design-build in the industry, especially in the public sector (Edmunds, 1992). Design-build contracts among the nation's top 400 contractors more than doubled between 1987 and 1990, going from $18 billion to $37 billion (Setzer, 1991). Ndedugri and Turner (1994) report that the use of design build is also increasing in the United Kingdom with greater acceptance among construction professionals but still meeting considerable resistance.

Design-Build in the Public Sector

Much of design-build's popularity in the private sector is due to it's increasing use in the federal government, especially among the General Services Administration (GSA), the Postal Service, and the Corps of Engineers (McManamy, 1994). The State Department, Department of Energy, NASA, and Veteran's Administration, have also used design-build contracts for a wide variety of facility types (ASCE, 1992). The GSA in particular had a large construction program spanning several years and planned to use design-build on many projects (Ichniowski, 1991). But protests by unsuccessful proposers, angry over high costs and vague selection criteria, have caused the GSA to back off its plans while reforming its procedures. In 1991, 21% of State Department projects were design-build or turn-key, as were 22% of Postal Service projects, 33% of

General Services Administration projects, and 93% of Environmental Protection Agency projects (ASCE, 1992). Until recently the Defense Department was limited by Congress to three design-build projects per year. That restriction was lifted in 1992, opening the way for dozens of military design-build projects (Heery, Thomsen, and Wright, 1993).

Since design-build is appropriate for a variety of project types, public agencies should develop criteria for deciding which projects are well-suited for it. The American Institute of Architects (AIA) and the Associated General Contractors of America (AGC) recommend these criteria include; project time constraints, design-build experience of potential project teams, and management capabilities of the owner agency and its personnel (AIA/AGC, 1995).

A 1990 report produced by the Corps' Construction Engineering Research Laboratory (CERL) describes design-build contracting procedures used for military construction. The Corps uses two varieties of design-build contracts, referred to as one-step and two-step. The main difference between them is the basis for contract award. In one-step projects, the Government produces a request for proposals stating project requirements and criteria, as well as evaluation factors. The Government then evaluates each proposal based on a number of factors including technical quality and cost before awarding a contract. In the two-step process the Government issues a request for technical proposals. The proposals are evaluated for conformance to the technical requirements of the request. Conforming proposers are then invited to bid and the contract is awarded to the low bidder (Napier and Freiburg, 1990). Songer, Ibbs, and Napier (1994) have developed a process model for public-sector design-build planning.

ASCE's Task Committee on design-build has addressed three key issues that deal specifically with design-build in the federal sector. One is the heavy cost burden placed on design-build teams to prepare detailed proposals for design build projects. These proposals can cost thousands of dollars to produce, but federal agencies rarely reimburse

unsuccessful teams. ASCE recommends that federal agencies provide clearly defined requests for proposals and use prequalification to limit the number of offerors. The AIA/AGE Task Group agrees, adding that unsuccessful bidders should receive a stipend to partially reimburse their expenses. They also emphasize that proposal requirements should be limited to control costs (AIA/AGC, 1995).

Some federal technical professionals have expressed the fear that more design-build projects might result in cutting some of their jobs. The task committee believes that the need for well defined requests for proposals, technical review and evaluation, and project management may actually require more of these government professionals (ASCE, 1992).

A third issue is the lack of a consistent approach to design-build among federal agencies. ASCE recommends that the federal government limit itself to two or three design-build variations to reduce the confusion and difficulty for design-build entities working with multiple agencies (ASCE, 1992).

The AIA and AGC have teamed up to write "Recommended Guidelines for Procurement of Design-Build Projects in the Public Sector", which should help in this regard (AIA/AGC, 1995). The owner's request for proposals should clearly define the procedures for contractor selection and for management of the project. It should identify the owner's representative and include a copy of the contract the successful proposer is expected to sign. The solicitation should also include a scope of work that contains; a detailed facility program, equipment requirements, other technical requirements, site information, any special government requirements, a preliminary budget and schedule. A flexible scope of work will elicit creative responses, prevent wasted preliminary design effort, and reduce the likelihood of protests by unsuccessful bidders (AIA/AGC, 1995).

The AIA/AGC guidelines recommend a two-step selection process. The first step is prequalification to arrive at a short list of 3-5 competitors. This allows for competition

and prevents the selection panel spending unnecessary time and money. It also prevents unqualified competitors from wasting their time and money in producing a proposal. Qualifications should include; competitor design and construction capability, past performance of individual team members, relevant experience as a team, and financial capacity to perform.

The government should clearly spell out final selection criteria in advance so competitors know where to place their emphasizes. Final selection criteria usually include; quality of the proposed design and construction approach, satisfying the program requirements, project management plan, and proposed cost. Owners must determine the relative value they place on price in advance. Owners more concerned with design quality can ask the competitors to provide the best design possible for a fixed budget. Those more interested in price can select a qualified competitor based on the lowest cost (AIA/AGC, 1995).

After final selection, it is important to provide useful feedback to unsuccessful teams. They will naturally want to know why they were not selected and how they can improve their chances for future projects. The AIA and AGC suggest that a detailed debriefing prevents bid protests and shows teams they were treated fairly (AIA/AGC, 1995).

In 1991, the Air Force commissioned Engineering Science, Inc., to study the success of five of its early design-build projects compared to traditional design-bid-build projects. The study examined the five projects in detail but did not actually compare them to similar traditional projects. The authors concluded that the design-build projects were generally successful over a variety of project types, were responsive to user's changing needs, saved time, and exposed the government to less risk. The authors also pointed out that design-build management costs were higher, and that the government had difficulty

responding to submittals fast enough to keep pace with the design-build contractor (ES, 1991).

The design-build joint-ventures building two prominent projects in Manhattan for the General Services Administration (GSA) praised this approach. "They forced us to be a team, and it worked" says one contractor working on a courthouse project, while a structural engineer involved with an office tower project nearby says design-build "enabled input from the contractor up front and all along" (Post, 1994).

The Federal Construction Council's Committee on Cost Engineering performed a study of 27 design-build projects in the Air Force, General Services Administration, NASA, U.S. Postal Service, Jet Propulsion Lab, Corps of Engineers, and Veterans Administration (FCC, 1993a). Although the study was based on subjective questionnaires and did not test results for statistical significance, it provides useful information on federal agencies' perceptions of design-build. As a group, the agencies found the design-build projects "somewhat better" than traditional projects in user satisfaction, planning and programming costs, design costs, construction costs, overall costs, number of change orders, other contract problems, design time, construction time, and overall time. They found design-build projects to be "about the same" in terms of functionality, quality, contract administration costs, and planning and programming time. The authors also examined the impact of facility type, location, contract amount, type of contractor, and percent designed before award on agency perceptions of design-build projects (FCC, 1993a).

The Construction Directorate at the Army's Community and Family Support Center has used design-build for approximately 30 projects in recent years. Their design-build projects averaged 12 months for construction and 21 months for total project duration, while their traditional projects averaged 15 months construction and 33 months total duration. Design-build projects also averaged $170,000 in cost savings. For design-

build projects, design, contingency, and administration averaged 16% of total project cost compared to 23.75% for traditional projects (Beauclaire, 1994).

A recent Navy project may point to the future use of design-build in military construction. The project was under extreme time pressure due to a base closing. This caused the Navy to reconsider many of its assumptions and normal design-build procedures. From the beginning, the Navy used an "acquisition team" made up of personnel from contracts, project management, engineering, and the field construction office resulting in an innovative approach to design-build. In an effort to speed the process and reduce the burden on offerors, the Navy contract included these features:

- a request for proposal of only 18 pages
- five evaluation factors
- a maximum of five drawings per proposal
- a maximum of 50 pages per technical proposal
- oral proposals by one-hour video tape

The Navy further reduced the burden on proposers by completing the selection process in only a week (Zimmerman, 1995).

Heery, Thomsen, & Wright (1993) discuss flaws in the design-build process as used in the Department of Defense. The biggest weakness in design-build, they argue, is the potential for conflict of interest. The design-build organization is supposed to be designing a project that will best meet the owner's needs, while trying to keep their own costs below the contract amount. The authors also point out that the owner has to define the project requirements, without the assistance of an A/E, before selecting a design-build firm. However, most federal agencies have large engineering staffs capable of producing preliminary design work and a request for proposals.

They describe a modified version of design-build they call "bridging". In bridging, the owner hires an A/E to prepare contract documents which include a detailed request for

proposals with performance specifications and drawings, called "design guide illustrations" (Heery, Thomsen, & Wright, 1993). The design-build team goes on to complete the design and construct the project. Usually, the owner's A/E serves as the owner's consultant and does not become part of the design-build team, but the owner must spell out the limits of each party's responsibilities. Some of the public-sector design-build issues identified above do not apply to bridging since the second phase submittal includes little, if any, design work, and final selection is usually based on price (AIA/AGC, 1995). Large international contractors have successfully used the bridging approach (Heery, Thomsen, & Wright, 1993).

E. Constructability

Throughout the late 1980's and early 1990's there have been a steady stream of articles and other publications about constructability. James T. O'Connor at The University of Texas, in particular, and others have systematically studied one aspect of constructability after another, including "Collecting Constructability Improvement Ideas", "Constructability Improvements During Engineering and Procurement", "Industrial Project Constructability Improvement", and "Constructability Improvement During Field Operations."

By 1991 so much work had been produced that the Construction Management Committee of the ASCE Construction Division felt the need to produce a "White Paper" on constructability and constructability programs. Among their conclusions,

> *Experienced construction personnel have provided input into construction projects for many years. However, only recently, under the impetus of the Business Roundtable's Construction Industry Cost Effectiveness Study, have the benefits of a constructability program received widespread recognition for their savings of time and cost, and their quality improvements. To receive maximum benefits, the construction input, or constructability, has to be*

> *started at the earliest stages during the conceptual planning stages. . . This paper emphasizes that the integration of experienced construction personnel into the earliest stages of project planning as full-fledged members of the project team will greatly improve the chances of achieving a better quality project, completed in a safe manner, on schedule, for the least cost* (ASCE, 1991).

In the meantime, the CII Constructability Task Force began to bear fruit and produced several works including, "Constructability - A Primer" (1986), ""Guidelines for Implementing a Constructability Program" (1987), "Project-Level Model and Approaches to Implement Constructability" (1992), "Benefits and Costs of Constructability: Four Case Studies" (1992), "Constructability: Program Assessment and Barriers to Implementation" (1993), and ""Preview of Constructability Implementation" (1993).

Taken together, this body of work has documented several conclusions, including:

- The greatest potential for constructability impact is in the early stages of design (CII, 1986). People with construction knowledge and experience must be involved in the early project stages to achieve maximum benefits (CII, 1993).
- In-depth integration begins with full commitment by the owner and should include the support of the entire project team (CII, 1986).
- Case studies using front-end constructability efforts have documented significant reductions in total project cost and schedule of 4.3 percent and 7.5 percent, respectively. These savings represented a 10 to 1 return on owners' investment in constructability (CII, 1993).

Despite its proven success and the potential savings it offers, constructability programs have been adopted inconsistently throughout the industry. For example, based on an extensive review of 62 companies claiming to have a constructability program, only two were found to have a comprehensive, formal program (CII, 1993). In proposing a model for implementing a project-level constructability program, Radtke and Russell have classified the wide variety of constructability programs in use today into eight approaches.

They range from historical practice in which no distinction is made between constructability and "good construction-management practices", to a formal program with comprehensive tracking of constructability savings and lessons learned (Radtke and Russell, 1993).

Of the eight approaches, the one most common in public-sector construction is called "constructability design review". It includes reviews of drawings and specifications at set design milestones (e.g., 30%, 60%, 90%, or final design) using formal checklists. This approach can provide useful constructability comments but only in reaction to a proposed design rather than having constructability as an integral part of the design process. Unfortunately this approach also tends to build an adversarial relationship between designers and those commenting on "their" designs, rather than putting them all on the same team. This research will consider the "constructability design review" approach part of the traditional design and construction process. Projects must go beyond this approach to be considered in the constructability category for case study projects.

1. Barriers to Implementing Constructability Programs

The main reason constructability programs have not been universally embraced in the design and construction industry are the barriers found in design, contractor, and owner organizations. Some of these barriers are cultural and some are contractual. Both the Business Roundtable and the CII have examined this issue. After surveying those in the industry who have tried to implement constructability programs they each compiled lists of barriers. Among the barriers common to both lists are:

- Tradition, complacency
- Reluctance by owners to add extra cost
- Lack or personnel with construction experience
- Resistance by engineers who don't respect constructors

- Contractor's input is not requested or contractor has no incentive to give input
- Lack of constructability awareness and training
- Low priority, lack of commitment to project integration (BR, 1982, O'Connor & Miller, 1993).

The same CII document that presents the list of barriers also provides a toolbox of "barrier breakers" to assist in implementing constructability programs. For example, "Limitations of Lump-Sum Competitive Contracting", is one of the biggest barriers to constructability for public owners. The CII report suggests the following barrier breakers:

> *A. Owner/designer acquire in-house construction expertise as input during design.*
> *B. Owner/designer procure out-of-house construction expertise as input during design.*
> *C. Use only A/E's with strong constructability capabilities.*
> *D. Document/disseminate cost-benefit data to disprove the low-bid economy mentality.*
> *E. Understand the benefits and flexibility of negotiated contracts and acquire skills to manage same; include constructability as a reimbursable service.*
> *F. Develop a short list of contractors who offer constructability input in return for the opportunity to be on the short list of bidders.*
> *G. Focus on optimizing the project rather than optimizing the design phase* (O'Connor and Miller, 1993).

2. Additional Barriers to Implementing Constructability in the Public-Sector

There are a number of barriers that especially hinder constructability program implementation for public agencies. As mentioned above, the biggest barrier to using a comprehensive constructability program in public construction is the traditional practice of:

- sealed bids based on a complete set of drawings and specifications
- low-bid awards, and
- firm-fixed-price contracts.

This arrangement does not normally allow the possibility of the contractor becoming involved in the project until after design is complete and the contract is awarded.

For this reason, many in federal design and construction agencies have not taken a serious look at constructability and other integration methods. In a 1985 report, the Federal Construction Council stated,

> *most agencies have no plans to implement those Business Roundtable recommendations that call for owners to take actions aimed at forcing contractor to adopt certain management techniques that the Business Roundtable believes will save money. Federal agencies believe that the use of competitively-bid fixed-price contracts provides ample incentive for contractors to seek more efficient methods of operation and that it is generally not necessary or appropriate for agencies to dictate the use of specific management techniques in order to reduce construction time and costs* (FCC, 1985).

The Logistics Management Institute, in a study titled "Contracting for Quality Facilities" noted,

> *Contracting officers currently find it difficult to depart from traditional contracting. They are discouraged by real and perceived barriers in the Federal Acquisition Regulation (FAR) and, more significantly, by Military Service rules, regulations and policies. They are also hampered by massive documentation requirements and lengthy approval processes* (Moore and Neeve, 1987).

The same report goes on to advocate greater flexibility in procurement strategies for the contracting officer as a way of achieving improved quality. The authors recommend competitive negotiation to make past performance count in contractor selection, and the use of award fees to promote performance improvement on current projects. They point out that many of the recommended alternative contractual arrangements are not really prohibited by the FAR, but specifically allowed under certain circumstances (Moore and Neeve, 1987).

An example of more comprehensive constructability in the public sector comes from the Naval Facilities Engineering Command (NAVFAC). NAVFAC's Southern Division decided that a $14 million propulsion training facility at Charleston, S.C., was going to be complex enough to require special attention. They followed one of CII's suggested barrier breakers from above, and advertised for contractors interested in participating in the design process and bidding on the project. Nine contractors responded and four were prequalified based on criteria such as experience, past performance, bonding/insurance capacity, and design support. The contractors provided constructability input throughout the project's design in return for being on the short list for bidding with reduced competition. Not only did this reduce costs through constructability ideas, but the bidders' thorough understanding of the design allowed them to reduce contingencies they would normally include in their bids. As a result, the bids were lower and very close. All three unsuccessful bidders said they considered the process successful and would like to participate in similar future projects. The Navy seems pleased with this approach and plans to use it again on other projects (Collins and Sellers, 1993).

The same organization is also drafting a new statement of work for design contracts that will require A/E firms to perform constructability either in-house or by hiring a consultant (Miller, 1993). This is another approach to bringing construction knowledge into the design process and makes use of another one of the suggested barrier breakers.

The Army Corps of Engineers Galveston District has tried yet another approach to constructability. They hired the Construction Industry Institute (CII) to do a constructability study of a major civil works project during design. The Sargent Beach project is a $60-70 million erosion control effort to protect part of the Gulf Intercostal Waterway in Texas. CII began the study by inviting interested contractors to attend (at their own expense) a one-day symposium where they learned about the project and made

recommendations. One participant characterized the symposium as having lots of good interaction between Corps designers, the CII team, and the 7 participating contractors (Tomlinson, 1994). CII analyzed the proposals, met with Corps designers and project managers to get their reactions, and formulated recommendations for the District. Participating contractors also received a copy of the study team's report. This type of arrangement benefited both the owner and the contractors. For the Corps, it developed contractor interest in the project, gained valuable feedback from, and improved relations with, the contractors. The contractors were glad to learn about the project, have an opportunity to give design input, and to interact with other contractors. The study team would have liked to hold the study earlier in the design phase before owner commitment to any particular design (Wood and Flanigan, 1995). One contract manager estimates this constructability exercise saved the project at least $2.5 million (Tomlinson, 1994).

F. Measuring Project Performance

There is no standard method for measuring project performance, success, or quality, but numerous researchers have proposed a variety of methods.

Sanvido et al point out that each project participant has different criteria for a successful project. They attempted to list success criteria for owners, designers, and contractors. As mentioned in Chapter I, they developed a list of criteria common to all three parties; on time, on budget, no legal claims, and profit or fee goals met (Sanvido et al, 1992).

In advocating greater use of constructability, the Construction Industry Institute has typically measured cost and schedule savings in case studies (CII, 1986).

In their studies of partnering in military construction, Weston and Gibson, and Schmader measured a wide variety of project performance indicators. Among them were

cost growth, schedule growth, change orders, value engineering savings, and claims (Weston and Gibson, 1993, and Schmader, 1994).

Fergusson and Teicholz have developed an industrial facility quality measurement technique based on owner attitudes and validated it by correlation with plant production for 17 industrial plant projects. The owner attitudes were measured by interviewing three groups within the owner organization; project management, strategic, and operations. Members of these groups rated projects based on 25 industrial facility quality factors (Fergusson and Teicholz, 1994).

The Department of Defense attempted to measure customer satisfaction through a large-scale questionnaire program. They received replies from 2,664 customers on 274 new facilities. The questionnaire was designed to prompt written comments. It included eight questions, such as; How well does the facility meet your need?, Was the right facility planned/designed?, and Was the planned/designed facility built right? (DOD, 1993)

G. Summary of the Literature Survey

Fergusson's classification of integration into a three dimensional framework helps us understand its attributes. However, there is still no objective method for measuring or quantifying project integration.

The value of the alternative approaches sounds promising but remains unproved. The two studies of partnered vs. traditional projects in the Corps and Navy come closest to satisfying this need. They include enough projects of both types to reach convincing conclusions about the increased success of partnered projects. Many more partnered projects have now been completed in the public-sector, including those using partnering in design.

Despite this increased use of design-build, it does not appear to be a "hot" topic in research. Design-build articles in academic literature were relatively rare. Most of the information came from trade journals, government reports, and professional association policy papers. There does not appear to be a scholarly study aimed at validating the success of design-build.

Although CII's claims for constructability may be valid, they are based on very small sample sizes. First, CII only describes case studies where constructability provided time and cost savings. Most of their works mention only four to eight case studies. Only one or two have been public-sector projects. This approach is understandable given that the type of constructability program CII advocates is still new and quite rare.

As described above, each of these approaches has been demonstrated to have strong potential and work well for some situations. No comprehensive attempt has been made to measure the success of projects using these approaches compared to traditionally designed and built projects.

This research attempts to address each of the following needs:

- While one can say, for example, that some design-build projects have been quite successful, no one has attempted to show with objective data that they tend to be consistently more successful than traditional projects. The studies by Weston and Gibson, and Schmader on partnered projects are the only exceptions found in the literature. There is still a need to compare design-build, constructability, and combination projects to traditional projects, and to validate the results for partnered projects.
- Another question not yet answered is which of these approaches to project integration, or which combination of them, seems to give the most successful result? In other words, how does the success of these various approaches compare to each other?

- Going a step further, which of these approaches offers the best opportunities for improved project integration?
- And finally, is there a direct correlation between improved project integration and performance?

CHAPTER III

METHODOLOGY

A. Scope

This research examines the performance of several different approaches to improving project integration. The methodology includes case studies of traditionally managed projects, comparing their performance with projects using partnering, design-build, constructability, and a combination of these approaches. Performance is measured by a combination of objective factors, including; cost, schedule, contract modifications, design deficiencies, claims, value engineering savings, safety, and user satisfaction. The null hypothesis is that there will be no significant difference in the performance of traditional projects and any of the alternative category projects. The alternative hypothesis is that the average performance for each of the alternative approaches will be significantly better than for the average traditional project.

It has long been believed that interaction among different parties in a construction project directly impacts the project's performance. There has been a lack of quantitative research to directly support or negate this belief. This research defines **"degree of interaction"** as an approximation of project integration, and develops a method to measure it. Furthermore, it examines the relationship between degree of interaction and project performance. The null hypothesis is that there will be no correlation between the degree of interaction and project performance. The alternative hypothesis is that there will be a clear correlation between degree of interaction and project performance.

Realizing that project integration is not directly measurable, interaction is used as a quantifiable substitute. ***Degree of Interaction*** **(DOI)** is defined as **the extent of interaction among designers, builders, and project team members during a project's**

planning, conceptual design, detailed design, procurement, construction and start-up phases. Not only is interaction measurable, but its extent is essentially the opposite of the fragmentation in the project delivery process described in Chapter I. DOI is calculated for individual projects by adding weighted interaction for each project phase.

Data were collected from 209 recently completed military construction projects including traditional and alternative approaches. Military construction was the source of case study projects because they are well-documented and project files are accessible. Project performance is analyzed by category, based on data from all 209 projects. DOI scores are calculated for 38 of these projects, representing some from each category. DOI scores are also analyzed by category. In a series of scatter diagrams, performance data are plotted against DOI scores for the 38 projects to demonstrate a relationship between the two. The relationship is verified based on the scatter diagrams and regression analysis. The relationship is further examined and verified by dividing the projects into those with "high" and "low" DOI scores. Finally, statistical and probabilistic analyses show how DOI can be used to predict future project performance. See Figure 3.1 for a flow chart of this methodology.

B. Data Sources and Collection

Data sources had to provide projects using the traditional approach and each of the alternative approaches. For statistical reasons, a goal of the research was to find at least 20 projects in each category. Military construction projects proved to be a good data source, due to the consistency and availability of project records. Because of intense congressional oversight, military construction projects have more consistent contracting and management procedures than private sector and other types of public sector projects. Hundreds of project records were available directly from the military services' data bases,

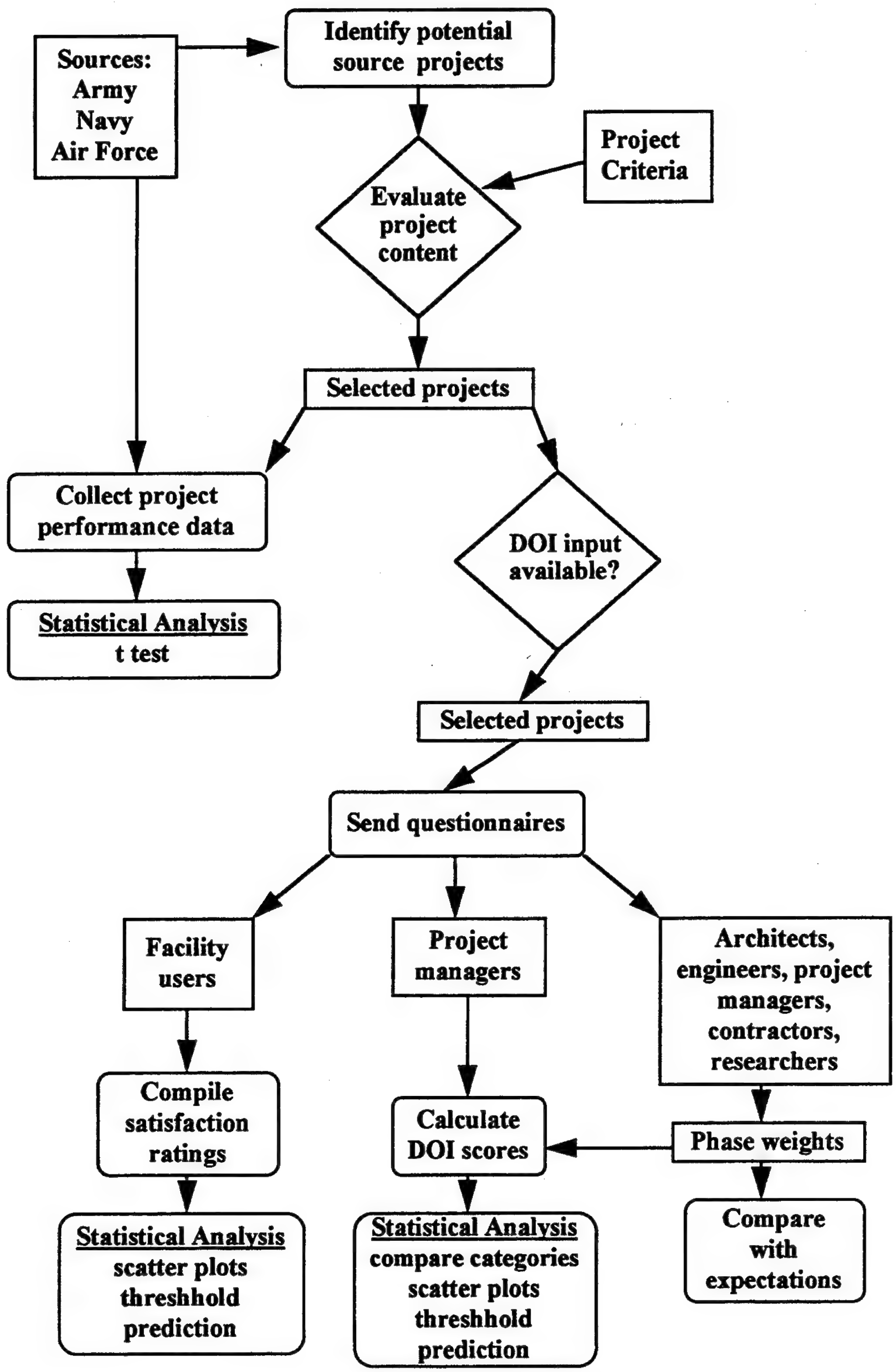

Figure 3.1 Methodology Flow Chart

such as the Corps of Engineers' Automated Management and Progress Reporting System (AMPRS), described below. Projects could be randomly selected according to the desired criteria, without depending on an owner to select the projects. Many pieces of project information are recorded in the same format for every project. Military construction also represents a wide variety of public-sector project types and locations. Of the 209 projects in this work, there are 65 different facility types, located in 30 states.

All projects were selected using the following criteria:

1. Each project is located in the continental United States to avoid distortions by overseas costs.
2. The minimum project value was set at $500,000 to ensure each project had a reasonable amount of management attention.
3. All projects were completed recently, having been funded in FY 1988 or later.
4. No family housing projects are included in the study because of their different funding and contracting policies.

Project performance information was collected at the local project level, as well as from regional headquarters sources. Information from both sources was cross-checked to ensure its accuracy. AMPRS information was provided by the US Army Corps of Engineers Headquarters in Washington, DC. AMPRS, a huge data base, is the official progress report for the design and construction program of the Army Corps of Engineers. Project information is input and monitored at local, regional, and headquarters levels. Corps of Engineers project managers use AMPRS to document and monitor project design and construction progress, while some portions are open to A/E firms and contractors interested in potential business opportunities.

C. Project Performance Indicators

In considering which factors might best indicate project performance, those that were directly measurable and readily available were considered first. In addition to cost and schedule performance, other indicators considered include; number of contract modifications, percent of modifications due to design deficiencies, claims cost, value engineering savings, and safety information.

The performance of each alternative category is compared to the performance of traditional projects using a two-sample student's t-test. This test determines whether the two sample means are equal, or whether we can reject the null hypothesis. It also provides the variance for each sample, and gives a p-value. Using a significance level of 0.1, we can be confident that the difference in means is significant if the p-value is less than 0.1. The p-value is the probability that the null hypothesis would be rejected in error. A one-tailed p-value is used since the alternative approaches are expected to yield improvement or no change, as compared to the traditional approach, rather than worse performance.

User Satisfaction

User satisfaction is also of interest, but as a secondary measurement to verify objective performance results. Since satisfaction is necessarily based on subjective measures, this work begins with an objective basis for making conclusions, then considers user satisfaction. This compliments work done by Fergusson (see Chapter II) that is based on project quality and user satisfaction, rather than objective performance measures.

D. Degree of Interaction

1. Significant Parameters

Measuring DOI requires measuring both qualitative and quantitative aspects of interaction. The author developed a questionnaire (see Appendix) that includes both types of parameters. The questionnaire was designed to be brief and easy to fill out, while soliciting data that were quantifiable and objective. The selected parameters and their definitions are:

- Interaction Phase: the project phase(s) in which designers and builders had direct contact.
- Number of Persons: the number of persons who were involved in the interaction.
- Job Titles: the job title for each person involved in the interaction.
- Hours/Month: the approximate hours per month each person spent in interaction.
- Duration(Months): how many months the interaction occurred during each phase.
- Interaction Type: whether the interaction was by planned in advance or in reaction to problems.

The questionnaire also provided blank space on the second page and asked the respondent to answer two questions; 1) describe the most common content of the interaction between designers and builders, and 2) was there anything out of the ordinary I should know about the project?

Using Fergusson's integration framework as a point of reference, we see that this approach strongly emphasizes vertical (inter-function) and longitudinal (across time) integration, while having a weaker emphasis on horizontal (inter-disciplinary) integration. It also tends to emphasize Fergusson's organizational (humanware) coordinating mechanisms over technical (hardware and software) mechanisms.

2. Objectivity of Parameters

Next came the problem of how to evaluate data that was subjective and combine it with numerical data in producing a score. For example, the participation of various personnel in interaction could be weighted differently according to their management level. To minimize subjectivity and to simplify the process, DOI is measured using only the most objective data among the above parameters. Therefore, the interaction of all personnel, regardless of job title, is assumed to be equally valuable, and interaction resulting from problems is assumed to be just as valuable as scheduled interaction.

E. Measuring Degree of Interaction

1. Availability of Data

Thirty-eight projects were chosen from the 209 projects, and were collected randomly to include projects of each category and all three military services. To provide a reasonable level of statistical significance, detailed information on interaction was needed from at least 20 projects. Questionnaires were sent to government project managers who were intimately familiar with each project. These project managers would have been present during any direct interaction between designers and builders. For some design-build and combination projects, the government project manager deferred to the design-build contractor to complete some portions of the questionnaire. These usually involved the detailed design phase when much of the designer-builder interaction was internal. The 38 projects ultimately chosen were those for which the project manager was still in place, remembered the project well enough to complete the questionnaire, and was willing to provide the information.

2. Assumptions in Counting Interaction Data

To maintain consistency, the following assumptions were applied in counting interaction data from the questionnaires:

- When designers and builders interacted, all participants were counted, assuming they also contributed to the interaction.
- However, if designers and builders did not both participate, the interaction would be disregarded, because it does not go beyond the status quo of the traditional process.

3. Weighting Factors for Each Phase

To measure DOI each project was divided into six phases; planning, conceptual design, detailed design, procurement, construction, and start-up. There is no standard convention for dividing a project into phases. Architects and engineers divide projects differently or use different terms for the same phases. These six phases are adapted from an article by ASCE's Construction Management Committee (ASCE, 1991) and the guide document "Quality in the Constructed Project" (ASCE, 1990).

Researchers have long been aware that interaction early in the project has greater impact than in later phases (CII, 1986). Therefore it was necessary to assign weights to reflect the relative value of interaction in each phase. To do this as objectively as possible, 21 architects, engineers, contractors, construction managers, and researchers were surveyed. This questionnaire (see Appendix) asked them to assign relative value to interaction occurring in each of the project phases. Their responses were averaged to arrive at a weighting factor for each project phase.

4. Calculating DOI

A time-based method was used to combine the questionnaire results into a single DOI score for each project. DOI is calculated as the ratio between the weighted total man-hours spent on interaction and the construction duration. For each project phase, the weighting factor is multiplied by the man-hours of interaction. The products from each phase are summed and divided by construction duration, to give DOI. The following equation shows specifically how to calculate DOI.

$$\mathrm{DOI} = \frac{1}{CD} \times \sum_{k=1}^{n} Pk \times \left[\sum_{i=1}^{mk} \left(\frac{tik}{160} \right) \times Dik \right] \qquad (1)$$

where:

DOI = degree of interaction based on man-hours

CD = construction duration in months

n = number of project phases (6 in this method)

P_k = the weighting factor for each interaction phase, where $k = 1, 2, 3, \ldots n$

m_k = the number of persons participating in the interaction for each phase (k)

t_{ik} = the hours/month each person (i) spent in the interaction for each phase (k), where i = 1, 2, 3, . . . m

160 = the approximate work hours in a month

D_{ik} = the duration of each person's interaction in months, for each phase

There are two reasons for using construction duration rather than total project duration as the denominator in the equation. First, several project phases often include significant "dead time" while waiting for approval or funding, during which no work or interaction occurs. Furthermore, it is difficult to obtain total project duration because good records for all phases of projects spanning several years are often unavailable, while construction duration is always recorded. Therefore the project construction duration is

used based on the assumption that it is proportional to the scale of the project and it usually does not include significant dead time.

This method measures the equivalent number of persons interacting full-time over all project phases. In other words, if one designer and one builder interacted full-time throughout all six project phases, that project would have a DOI score of 2.0. A DOI score of 0.0 does not mean there was zero interaction. It does mean that the designers and builders on that project did not interact directly.

DOI scores were calculated by applying equation (1) to data from the questionnaires. An example for calculating a DOI score is shown in Table 2. Column 1 lists the project name and the phases for which interaction occurred. For each project phase with interaction, the weight factor (column 2), the number of persons (column 3), the interaction hours per month (column 4), and interaction duration (column 5) are multiplied. This product is then divided by 160 (approximate work hours in a month) and the construction duration (column 6). A subtotal is provided for each phase and the sum of the subtotals equals the total DOI score for the project.

F. User Satisfaction

Satisfaction information was solicited from the users of the 38 projects with measured degree of interaction scores. A short questionnaire (see Appendix) was used to measure user satisfaction. This questionnaire is adapted from those used by Fergusson and the Department of Defense. It asks the users about their satisfaction (on a scale of 1-10) with project planning/design, construction, and whether the facility meets their needs. If they are not satisfied, the questionnaire asks whether this is due primarily to design or construction problems. The users also have a space to provide comments. The results are used to supplement the objective project performance data.

Table 3.1 Example of DOI Score Calculation

Project Phases	Weight Factor (P_k)	Number of Persons (m_k)	Interaction (hours/ month) (t_{ik})	Interaction Duration (months) (D_{ik})	Construction Duration (months) (CD)	DOI Score
Planning	0.16	1	40	0.5	18	0.001
	0.16	3	100	0.5	18	0.008
Sub-total						0.009
Conceptual Design	0.22	-	-	-	-	0
Detailed Design	0.25	8	90	3.5	18	0.219
	0.25	2	40	3.5	18	0.024
Sub-total						0.243
Procurement	0.09	1	10	2	18	0.001
	0.09	4	40	2	18	0.010
Sub-total						0.011
Construction	0.22	22	10	14	18	0.235
Start-up	0.06	2	10	1	18	0.000
Total Score	1.00					0.499

CHAPTER IV

RESULTS AND ANALYSIS

A. Introduction

This chapter begins with comparing performance of the 209 projects by category. Performing *t* tests verifies significant differences in performance between traditional projects and the alternative approaches. Then the average DOI scores of the 38 projects are compared by category. Again, differences between the alternative and traditional categories are analyzed using *t* tests. Next, a series of four scatter plots compares project DOI scores to objective performance indicators. One scatter plot each is presented for DOI score vs. cost growth, schedule growth, number of modifications/million dollars, and percent modifications due to design errors. Scatter plots are also presented comparing project DOI scores with subjective user satisfaction ratings. Both types of scatter plots reveal an apparent relationship between DOI score and performance indicators, as verified by regression analysis. DOI results are also analyzed by comparing the difference in performance between projects with DOI scores above and below a threshold value. Again, *t*-tests verify the significance of differences. Finally, statistical probabilistic analysis of the "high DOI" and "low DOI" group averages allows us to predict future average project performance.

B. Project Performance by Category

The 209 projects in this study include 90 traditional projects, 63 partnering projects, 40 design-build projects, and 16 combination projects. There are no constructability projects. Every constructablity project identified also used either

partnering or design-build, so they were all classified in the "combination" category. The number of projects in each category roughly represents the proportion of each category in the total project population. Traditional and partnered projects are plentiful in military construction, while design-build, and especially combination projects, are rare. The majority of all completed military design-build and combination projects were included in this study in an effort to have adequate sample sizes. Each project category included several projects each from the Army, Navy, and Air Force.

Performance Indicators

Information was collected on all potential performance indicators, including cost and schedule performance, number of contract modifications, design deficiencies, claims cost, value engineering savings, and safety records. After collecting and examining project data, the results for claims and value engineering proved to be inconclusive. The great majority of projects studied had no claims and no value engineering savings, regardless of approaches used. The results for safety were often unavailable and were inconclusive when available. Most projects studied had no lost-time accidents. The cost, schedule, and modifications data proved more useful. They provided measurable differences between projects and categories.

This study uses four objective measures as performance indicators: 1) cost growth (percent difference between original and actual cost), 2) schedule growth, 3) the number of contract modifications per million dollars, and 4) percent of modifications due to design deficiencies.

The number of contract modifications per million dollars gives an indirect measure of how many problems the project encountered. While not every modification indicates a problem, and multiple items can be contained in the same modification, this will tend to be true for all projects, so the differences will be useful for comparison. The number of

modifications are divided by million dollars of contract value to normalize the effects of project size.

The percent of modifications due to design deficiencies is a direct measure of design quality. One would expect fewer design problems to surface on projects where builders had an opportunity to interact with designers early in the project. Government construction managers usually assign reason codes for each contract modification. This indicator counts only those modifications for which the assigned reason code was a design deficiency or error. The cause of each modification is sometimes open to interpretation, so the reason codes assigned are somewhat arbitrary. Even so, this is true of all projects, and with a large sample size, errors in either direction will tend to cancel each other out.

Complete information on contract modifications was not available on all projects because it is not maintained in long term data bases. As a result, modifications due to design deficiencies and, to a lesser extent, the modifications per million dollars are not available for all projects. However, all four performance indicators are available for most projects.

While these four indicators do not form a complete measure of project performance, they are certainly useful. They represent four aspects of project performance, reflecting concerns from all parties involved, especially the owner's. Table 4.1 summarizes the performance results for all 209 projects by category. A complete list of all 209 projects along with their performance indicators is included in Appendix A.

An analysis of each category was performed using the *t* test for samples with unequal variances. The null hypothesis is: sample means of the alternative approaches are not significantly different from those of the traditional approach. For each performance indicator, Table 4.1 lists the sample means, variance, and *p*-value. The *p*-value is the statistical probability that the sample means would be equal. Based on the results, each of

Table 4.1 Average Project Performance by Category

Performance Indicators	Traditional	Partnered	Design-Build	Combination
Cost Growth (%)	8.48	8.62	6.37	10.44
Variance	141	53	59	100
***p* (T<=t), one tail**	-	0.4648	0.1135	0.2460
Schedule Growth (%)	27.76	17.06	26.23	18.76
Variance	1099	553	1285	541
***p* (T<=t), one tail**	-	0.0145	0.4107	0.0978
Modifications per Million Dollars	8.30	6.88	6.80	4.95
Variance	37	26	36	7
***p* (T<=t), one tail**	-	0.0603	0.1081	0.0004
Modifications due to Design Deficiencies (%)	41.84	38.14	9.39	15.18
Variance	344	188	157	329
***p* (T<=t), one tail**	-	0.1253	6.93E-15	1.34E-05

the alternative approaches has a significant advantage over traditional projects for at least one performance indicator. Figure 4.1 summarizes these results graphically.

The results for traditional projects verify that there is certainly room for performance improvement. Average cost growth was 8.48% and average schedule growth was 27.76%. The number of modifications per million dollars averaged 8.30, while an average 42.27% of those modifications were due to design deficiencies.

Using a significance level of 0.10, the partnered projects have significantly less schedule growth, fewer modifications, and fewer design deficiencies than the traditional projects. The 17.06% average schedule growth for partnered projects was the lowest of all four categories. The variance for partnered projects is less than traditional projects in every performance indicator.

While having less cost growth and fewer modifications than traditional projects, the design-build projects do not quite meet the 0.10 significance level for these performance indicators. They do have significantly fewer design deficiencies, in fact design-build projects had the lowest cost growth (6.37%) and design deficiencies (9.39%) of all categories. Design-build projects had less variance in cost growth (59 vs. 141) and design deficiencies (157 vs. 335) than traditional projects.

The combination projects are significantly better than traditional projects in every performance indicator except cost growth. Cost growth averaged 10.44%, and was the only performance indicator for all three alternative approaches that did not improve over the traditional projects. It is not apparent why combination projects had higher average cost growth. They averaged the fewest modifications among the categories, at 4.88%. Combination projects have less variance than traditional projects for each performance indicator.

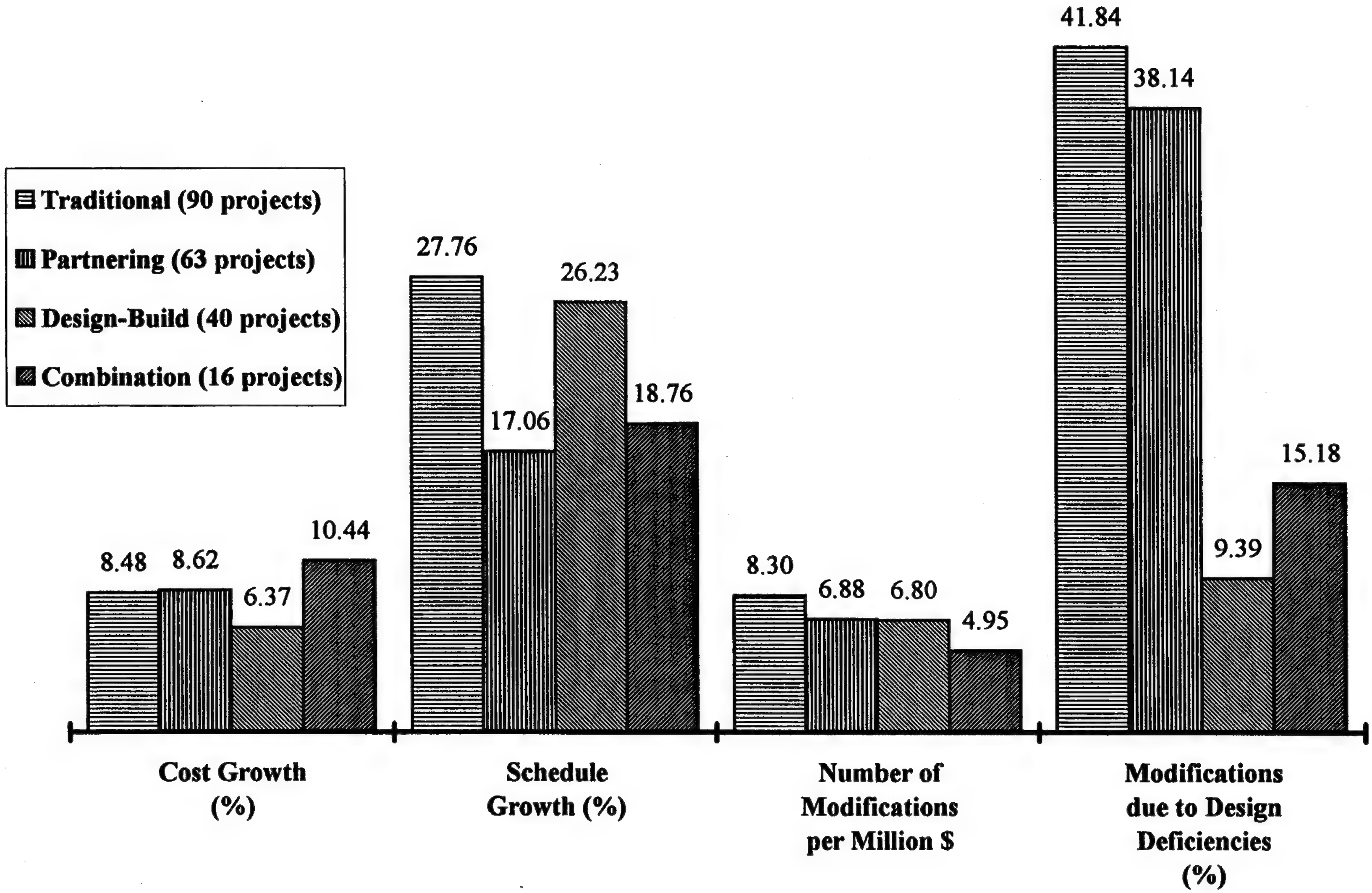

Figure 4.1 Averge Project Performance by Category

C. Calculating Actual DOI Scores

Before DOI scores could be calculated, phase weights had to be assigned to each project phase (see section E.3 in Chapter 3). Phase weights place greater or lesser emphasis on interaction during different project phases according to their relative value. Survey responses from architects, engineers, contractors, project managers, and researchers were used to arrive at weighting factors for each project phase. The final weighting factors are listed in Table 4.2 below. These weighting factors, however, can be adjusted by decision makers based on their own judgment. The weighting factors are directly used in calculating DOI scores, and represent the relative value of interaction between designers and builders in each project phase.

Table 4.2 Weighting Factors for the Relative Value of Interaction in each Project Phase

Phases	Weighting Factor
Planning	0.16
Conceptual Design	0.22
Detailed Design	0.25
Procurement	0.09
Construction	0.22
Start-Up	0.06

DOI project data were gathered from July 1994 to May 1995. 33 respondents provided 38 usable questionnaires for this research. Telephone interviews were conducted with the respondents to clarify incomplete or unclear answers on the questionnaires. Although the questionnaires are intended to solicit objective information on interaction, they depend on the memory of project managers and their estimation of hours spent in

interaction by each individual. Therefore, the results are partially subjective. DOI scores were calculated using questionnaire results and the methodology described above for the 38 projects. These include eight traditional projects, thirteen partnered projects, nine design-build projects, and eight combination projects. Table 4.3 lists each of these projects along with their degree of interaction score and performance indicators.

Sensitivity Analysis

Since the phase weights are based on expert opinion rather than objective data, a sensitivity analysis was performed to verify that the weights do not have disproportionate influence on DOI scores. To perform the analysis, a degree of interaction score was calculated for a typical project with moderate interaction across all project phases. As shown in Table 4.4 below, this results in a DOI score of 4.23. The factors that go into the DOI equation were then altered, one at a time, to measure the resulting change in DOI score. The results are listed in Table 4.5 below.

Changes in the weighting factors result in proportionately smaller changes in DOI score. Since the weight factors must add up to one, increasing some of them requires decreasing others. In this analysis, the three largest weight factors were each increased 25%, while the three smallest were reduced 25%. This resulted in a 21% increase in DOI score. Then the three largest weight factors were reduced 25% while the three smallest were increased 25%, yielding a 21% decrease in DOI score. The relatively small changes in DOI score are due to the cancelling effect of increasing some weights while decreasing others.

Changes in the next two factors, number of persons and the amount of interaction, give proportionate changes in DOI score. When the number of persons increases 25%, so does the degree of interaction. Reducing the amount of interaction 25% reduces the DOI score 25%.

Table 4.3 Project Degree of Interaction Scores and Performance Results

Project Descripton	DOI Score	Cost Growth (%)	Schedule Growth (%)	Number of Modifications / $ Million	Modifications from Design Deficiencies (%)	Average User Satisfaction (1-10)
Traditional Projects						
Bachelor Enlisted Quarters	0.094	5.07	20.65	4.71	50.00	3.0
Applied Instruction Building	0.000	7.98	19.17	2.25	86.67	
Flight Simulator	0.270	2.67	-9.44	19.48	35.00	6.5
Add/Alter Electric Substation	0.018	2.27	18.09	11.10	7.69	3.5
Shortfield Assault Strip	0.188	25.50	21.48	5.17	45.45	
Field Training Detachment	0.033	24.72	103.33	14.66	74.19	9.0
Flight Simulator Facility	0.027	8.54	60.12	24.22		8.5
Engine Inspection & Repair	0.055	21.39	74.44	28.65	65.00	5.0
Traditional Project Averages	**0.086**	**12.27**	**38.48**	**13.78**	**52.00**	**5.9**
Partnered Projects						
Explosives Handling Wharf	0.665	5.14	6.91	2.01	38.75	10.0
Replacement Hospital, Phase II	0.182	6.17	23.52	1.60		6.5
Drydock Modernization	1.030	13.92	1.28	3.27		9.0
Audio Visual Service Center	1.420	7.45	13.70	5.81	55.26	9.0
Fleet Headquarters	0.328	7.11	13.74	11.40	46.60	9.0
B-2 Avionics Facility	0.037	9.60	16.27	4.21	12.12	8.5
Urban Training Facility	0.286	14.42	-26.16	3.19		9.0
Landing Craft Support Facility	0.132	2.91	11.30	3.77	32.35	3.0
Armory	0.060	1.29	0.00	3.46	50.00	9.0
Air Operations Facility	0.031	3.86	5.36	1.97	20.00	6.0
Enlisted Dormitory	1.621	5.56	10.35	4.29	35.00	7.5
Dining Facility	1.666	4.27	14.05	8.34	24.24	6.0
LCAC, Phases 3 & 4	0.020	15.87	42.88	5.06	44.71	6.5
Partnered Project Averages	**0.575**	**7.50**	**10.25**	**4.49**	**35.90**	**7.6**
Design-Build Projects						
Health Care Facility	1.282	11.68	15.77	5.42	35.96	8.5
DLI Student Enlisted Housing	0.061	3.85	81.25	4.69	8.51	8.0
DLI Dining Facility	0.060	1.45	81.25	7.51	9.09	5.5
Child Development Center	0.026	-0.51	73.89	14.48	13.33	4.5
Child Development Center	0.245	18.44	33.65	9.43		7.5
Guest House	0.057	5.52	-22.22	1.76	0.00	3.0
Enlisted Club	0.083	9.74	12.96	2.74	0.00	9.0
Auto Craft Center Addition	0.143	4.69	84.87	9.95	0.00	7.0
Youth Activity Center	0.870	-0.38	17.78	3.85	0.00	8.0
Design-Build Project Averages	**0.314**	**6.05**	**42.13**	**6.65**	**8.36**	**6.8**
Combination Projects						
Sparkman Command Center	1.379	4.30	18.46	1.26	4.11	10.0
Propulsion Training Facility	0.904	6.19	45.96	7.11	25.21	7.0
Phase I Apron/ Hydrant	0.481	6.49	-15.28	2.91	28.95	7.0
Maintenance Docks & Hangars	0.499	7.43	7.30	3.18	0.58	
General Education Dev. Fac.	0.889	6.00	5.96	3.72	0.00	9.0
Shore Interm. Maintenance Act.	0.295	17.51	-0.82	9.42	26.80	8.5
Child Development Center	0.184	3.71	5.78	7.06	3.33	9.0
Child Development Center	0.176	7.36	65.67	7.33	11.76	9.0
Combination Project Averages	**0.601**	**7.37**	**16.63**	**5.25**	**12.59**	**8.5**

The two remaining factors that contribute to DOI score, interaction duration and construction duration, are not considered in the sensitivity analysis because they are not subject to management control .

Table 4.4 Typical DOI Score Calculation for Sensitivity Analysis

Project Phases	Weight Factor	Number of Persons	Interaction (hours/ month)	Interaction Duration (months)	Construction Duration (months)	DOI Score
Planning	0.16	12	16	2	18	0.021
Conceptual Design	0.22	12	16	3	18	0.044
Detailed Design	0.25	12	16	5	18	0.083
Procurement	0.09	12	16	1	18	0.006
Construction	0.22	12	16	18	18	0.264
Start-up	0.06	12	16	1	18	0.004
Total Score						0.423

Table 4.5 Results of DOI Score Sensitivity Analysis

Factor	% Change in Factor	% Change in DOI
Weight Factor	+25	+21
	-25	-21
Number of Persons	+25	+25
	-25	-25
Interaction	+25	+25
	-25	-25

Another approach to sensitivity analysis was also considered. As stated above, the phase weights are based on the expert opinions of architects, engineers, constractors, project managers, and academic researchers. The phase weights used are simply the average of the responses received. While there was general concensus among those surveyed, the project managers and academic researchers had the most different sets of

phase weights. Therefore, a comparison was made of the resulting DOI scores for the 38 projects, using the academic researchers' and project managers' phase weights. These DOI scores were then compared to those using the overall average phase weights, as listed in Table 4.6 below.

Using the different sets of phase weights did shift the DOI scores, but did not result in a significant change in the relative DOI ranking of individual projects. Using the academic researchers' phase weights reduced the average DOI score by 17.24%, but only 6 of 38 projects (15.8%) changed their rank order. The project managers' phase weights resulted in DOI scores that averaged 25.17% higher, but only 7 of 38 projects (18.4%) changed rank order.

Therefore, based on both approaches to this sensitivity analysis, we can conclude that the weighting factors do not have an unreasonable level of influence on the degree of inteaction score.

D. DOI Score by Category

Figure 4.2 shows the average project DOI score by category. Each of the alternative categories clearly has a higher average DOI score than the traditional projects. In fact the highest DOI score for a traditional project, 0.27, is lower than the average DOI score for each of the other categories. Partnering and combination projects have the highest average DOI score, 0.58 and 0.60 respectively, with design-build somewhat lower at 0.31.

DOI scores for traditional projects are in a narrow range from 0.0 to 0.27, with an average of 0.086. While they all have higher average DOI scores, using an alternative approach does not guarantee a higher DOI score. All three alternative approaches have a

Table 4.6 Comparison of DOI Scores Based on Different Sets of Phase Weights

Projects	Overall Average	Academic Researchers	% Change	Project Managers	% Change
Applied Instruction Building	0.000	0.000	0.00	0.000	0.00
Add/Alter Electric Substation	0.018	0.014	-22.73	0.024	36.36
LCAC, Phase 3 & 4	0.020	0.016	-19.61	0.028	35.58
Child Development Center	0.026	0.025	-5.50	0.024	-8.72
Flight Simulator Facility	0.027	0.021	-22.73	0.036	36.36
Air Operations Facility	0.031	0.024	-22.47	0.042	36.23
Field Training Det. Facility	0.033	0.026	-22.73	0.045	36.36
B-2 Avionics Facility	0.037	0.029	-22.47	0.050	36.23
Inspection & Repair Facility	0.055	0.043	-22.73	0.075	36.36
Guest House	0.057	0.052	-8.57	0.055	-3.20
Construct Armory	0.060	0.046	-22.73	0.082	36.36
DLI Dining Facility	0.060	0.056	-7.62	0.068	12.19
DLI Student Housing	0.061	0.056	-7.53	0.068	12.04
Enlisted Club	0.083	0.068	-18.82	0.107	28.80
Bachelor Enlisted Quarters	0.094	0.073	-22.71	0.129	36.35
LCAC Phase III	0.132	0.099	-24.98	0.143	8.34
Auto Craft Center Add.	0.143	0.134	-6.36	0.161	13.02
Child Development Center	0.177	0.156	-11.82	0.150	-15.15
Replacement Hospital, Phase II	0.182	0.141	-22.73	0.248	36.36
Child Develpment Center	0.184	0.157	-14.77	0.168	-8.98
Shortfield Assault Strip	0.188	0.145	-22.73	0.256	36.36
Child Development Center	0.245	0.196	-20.07	0.303	23.62
Flight Simulator Facility	0.270	0.209	-22.73	0.368	36.36
Urban Training Facility	0.286	0.221	-22.73	0.390	36.36
Shore Intermed. Maint. Act.	0.295	0.239	-19.07	0.388	31.72
Fleet Headquarters	0.328	0.255	-22.44	0.447	36.22
Phase I Apron/Hydrant	0.481	0.443	-7.96	0.542	12.79
Maintenance Docks/Hangars	0.499	0.461	-7.66	0.583	16.94
Explosives Handling Wharf	0.665	0.520	-21.71	0.905	36.11
Youth Activity Center	0.870	0.714	-17.86	1.061	21.95
General Education Dev. Fac.	0.889	0.753	-15.37	0.951	6.96
Propulsion Training Facility	0.904	0.784	-13.31	1.196	32.25
Drydock Modernization	1.030	0.798	-22.49	1.403	36.25
Comprhensive Health	1.282	1.140	-11.09	1.509	17.75
Sparkman Command Center	1.379	1.194	-13.40	1.560	13.14
AAVS Service Center & HQ	1.420	1.231	-13.34	1.724	21.40
Enlisted Dormitory	1.621	1.253	-22.73	2.210	36.36
Dining Facility	1.666	1.287	-22.73	2.272	36.36
Averages	0.427	0.353	-17.24	0.534	25.17

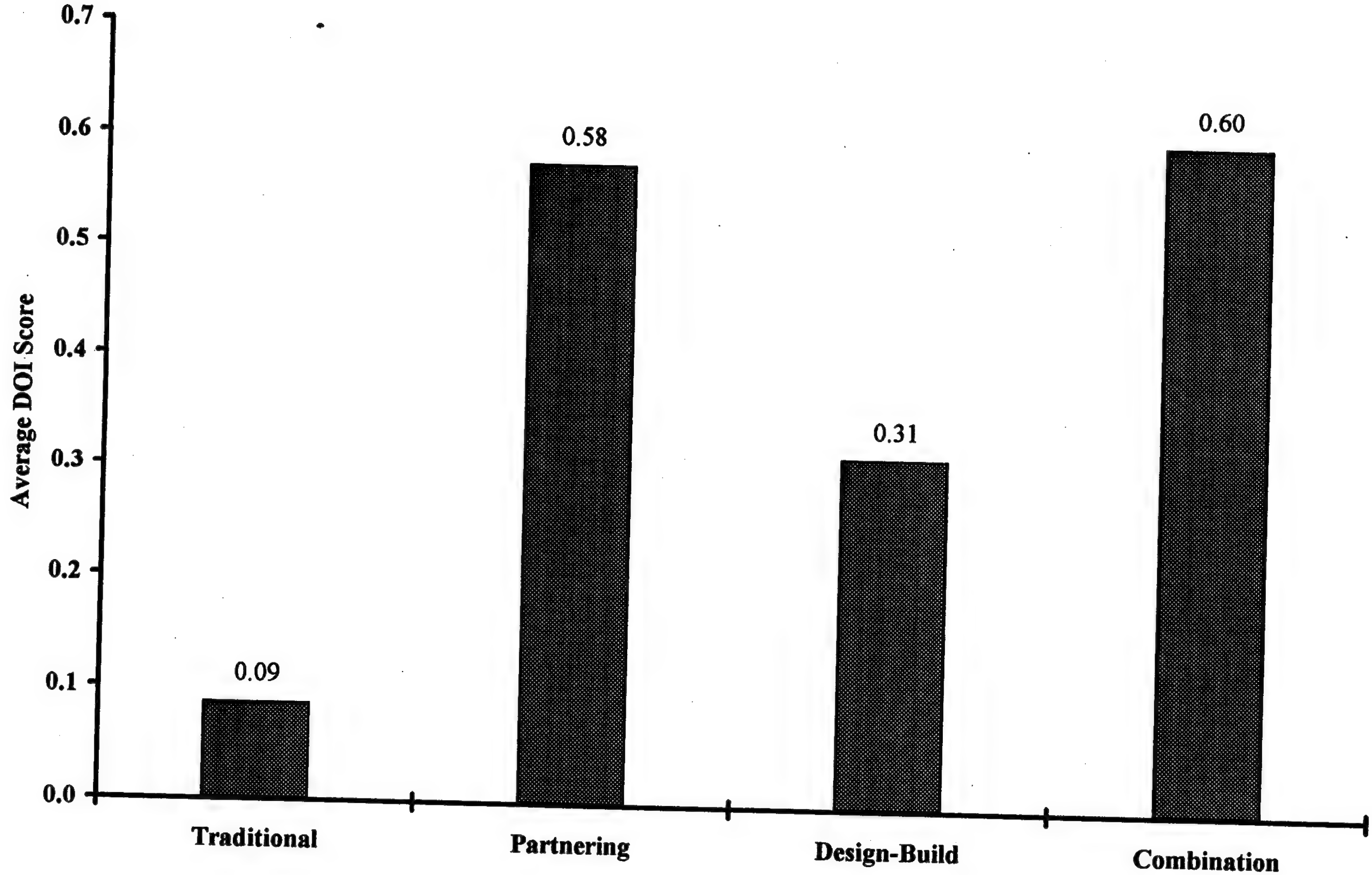

Figure 4.2 Average Project DOI Score by Category

wide range of scores. Partnered projects have the widest range of scores, from 0.02 to 1.666. Design-build scores range from 0.026 to 1.282, and combination projects range from 0.176 to 1.379. Figure 4.3 shows the range of DOI scores for each category.

These results show that although alternative approaches have higher average DOI scores, using an alternative approach does not guarantee increased interaction, they only provide the opportunity. However, using the traditional approach seems to guarantee a very low degree of interaction.

E. The Relationship Between DOI Score and Performance Indicators

We now turn our attention from the differences between categories to the direct relationship between degree of interaction and project performance. Four scatter plots were created based on the data in Table 4.3. Each of these diagrams plot DOI score against one of the performance indicators with each data point representing one of the 38 projects. They show the relationships between DOI score and cost growth (Figure 4.4), schedule growth (Figure 4.5), number of modifications/ million dollars (Figure 4.6), and modifications due to design deficiencies (Figure 4.7). In Figure 4.4, cost growth performance is widely scattered, including the best and worst, for projects with low DOI scores. As the DOI score increases, cost growth tends to improve and stabilize. Cost growth does not continue to improve with higher DOI scores, but levels off. The pattern is very similar for schedule growth in Figure 4.5. In fact, schedule growth may even get slightly worse for projects with the highest DOI scores. The same pattern is evident in Figure 4.6 for number of modifications per million dollars. Even though many projects with very few modifications are included in those with low DOI scores, the projects with the most modifications all have low DOI scores. The pattern is not as recognizable for modifications due to design deficiencies in Figure 4.7. Here the difference in design

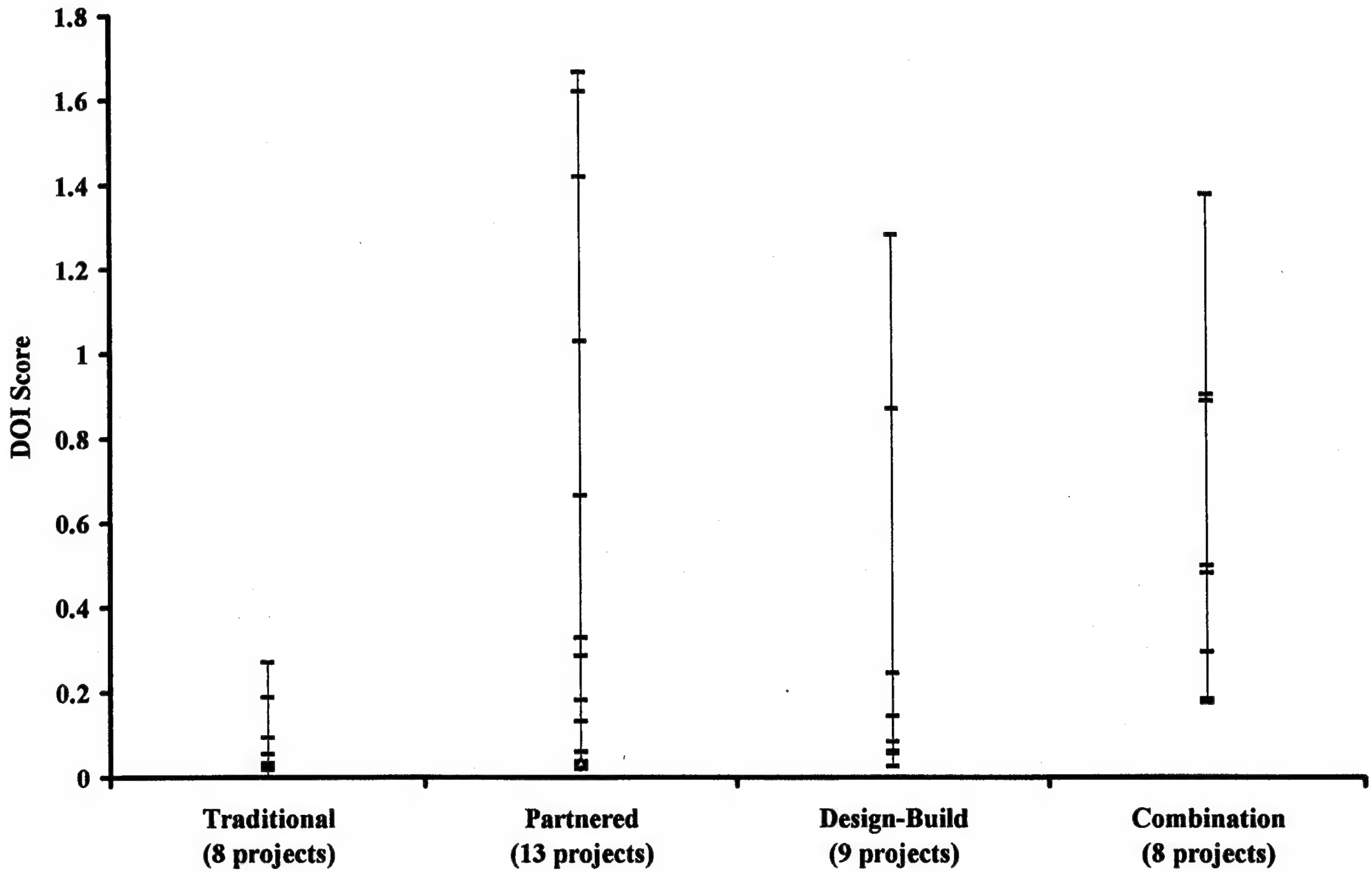

Figure 4.3 Range of DOI Scores by Category

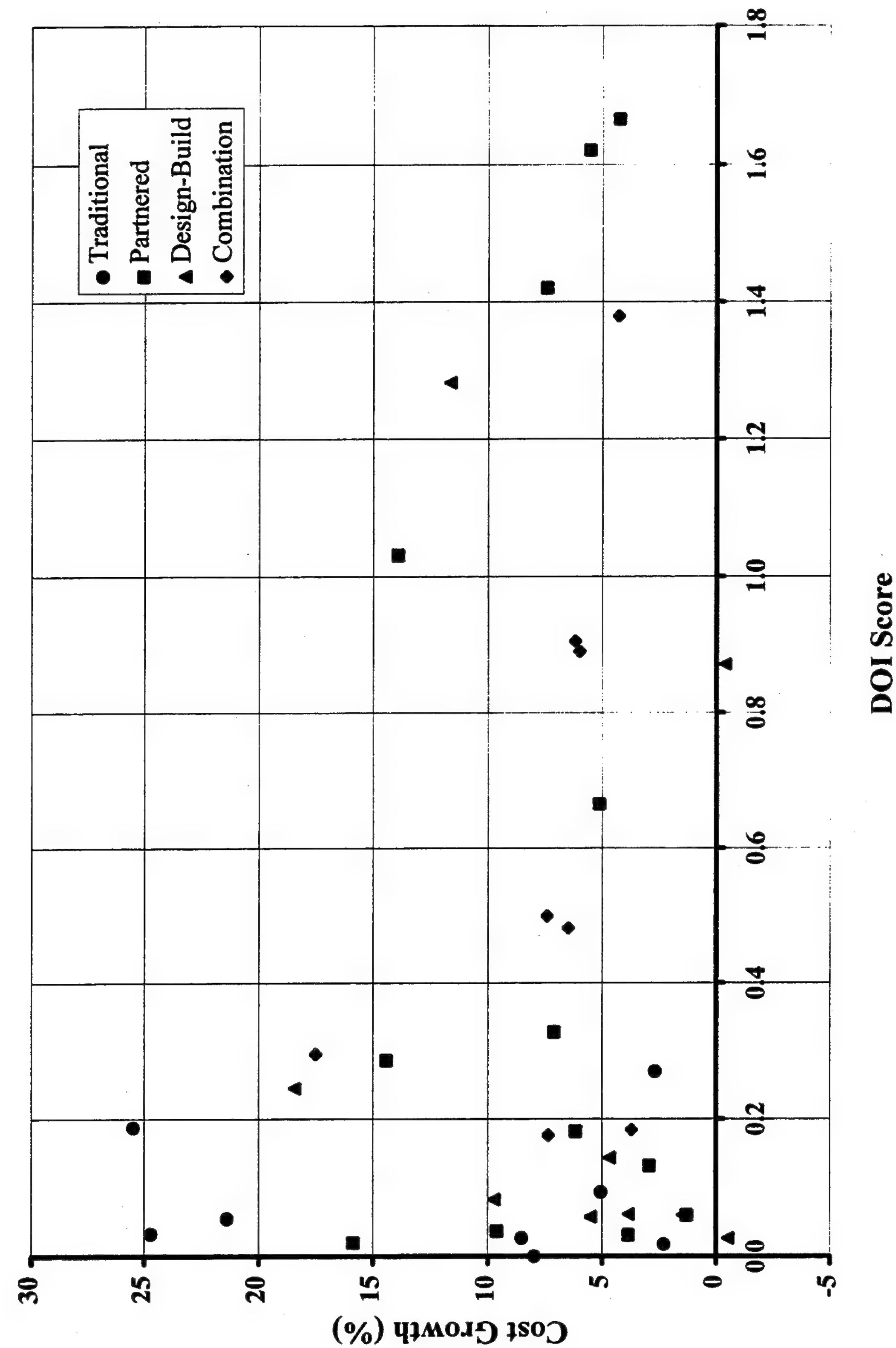

Figure 4.4 DOI Score vs. Cost Growth (%)

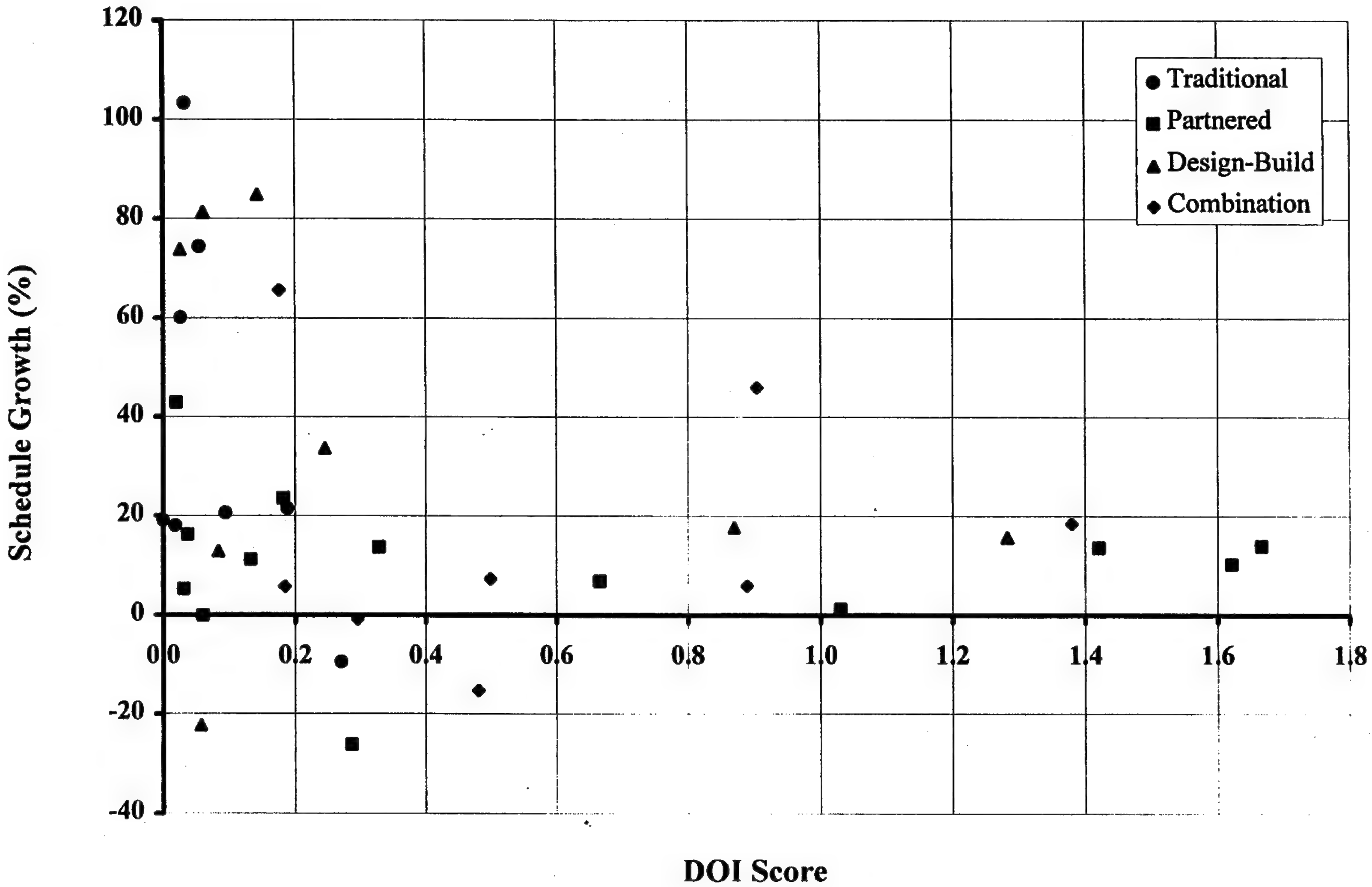

Figure 4.5 DOI Score vs. Schedule Growth (%)

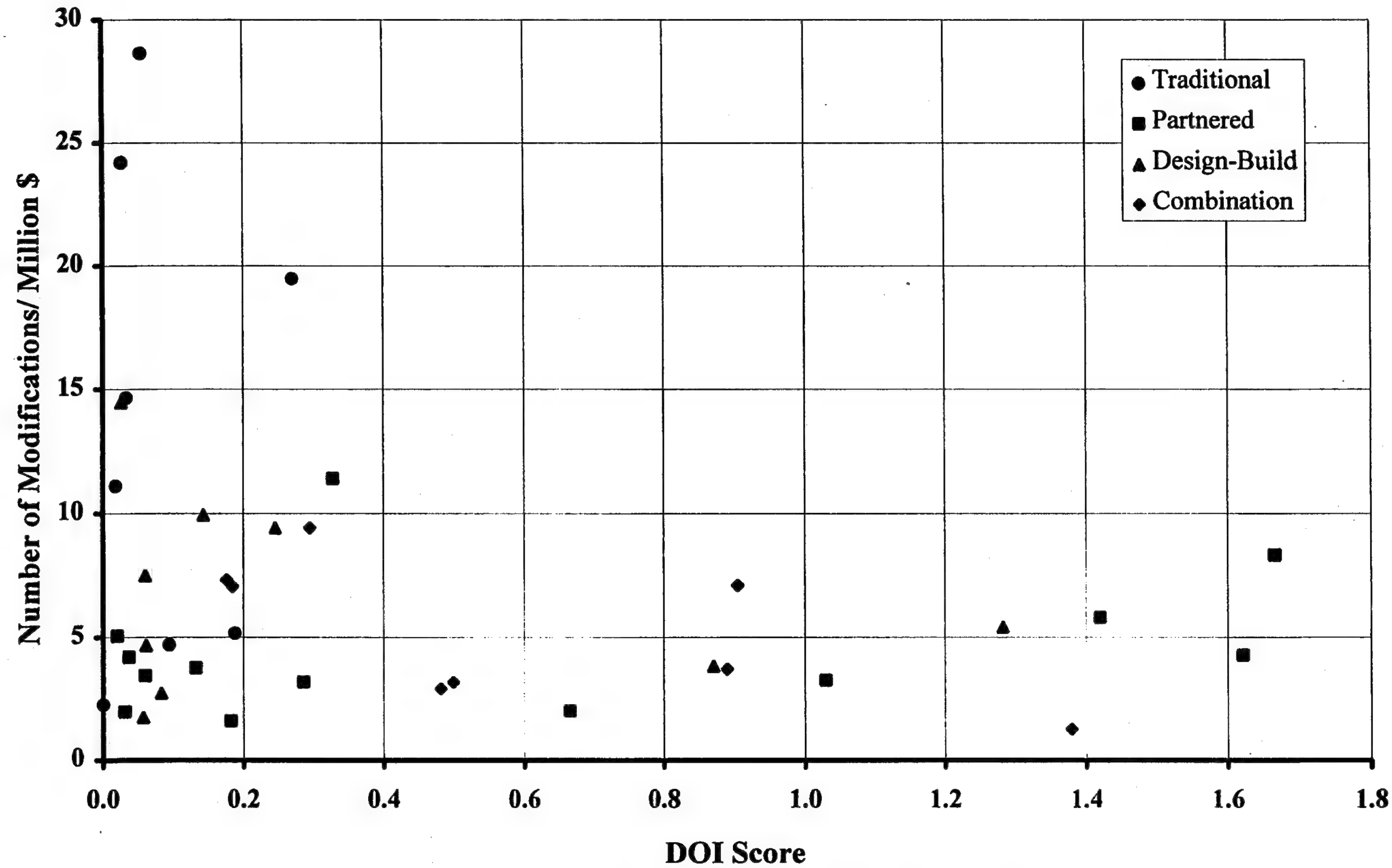

Figure 4.6 DOI Score vs. Number of Modifications / Million Dollars

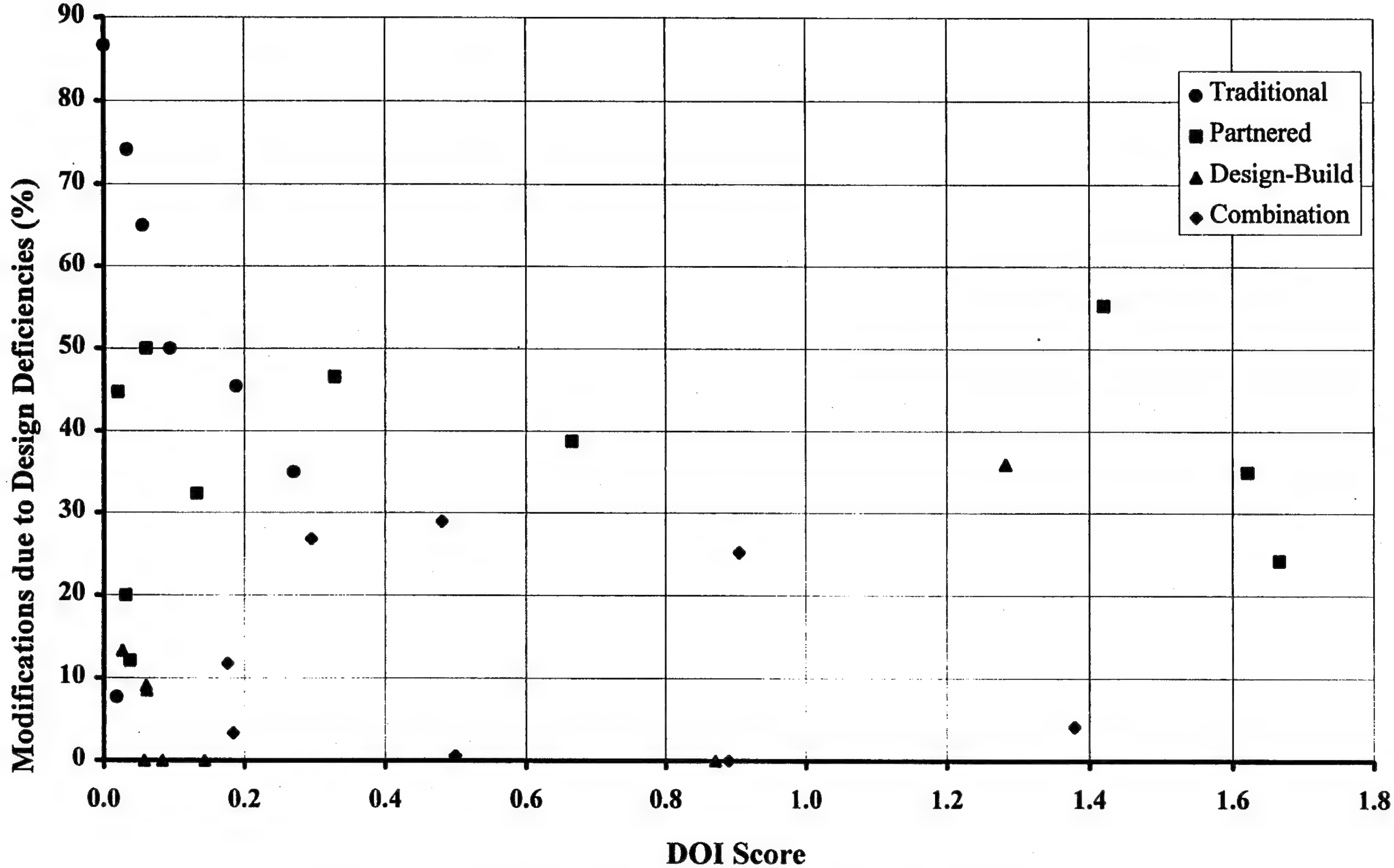

Figure 4.7 DOI Score vs. Modifications due to Design Deficiencies (%)

deficiencies between the projects with low and high DOI scores is not as great. This is the least objective of these four performance indicators.

Each of the scatter plots reveals the same general relationship between DOI score and performance. For projects with low DOI scores, there is a wide range of performance. But once DOI scores improve beyond a certain point, performance tends to both stabilize and improve. At very high levels of DOI, as the demands of interaction could detract from project management, performance may even worsen. In other words, projects with higher DOI scores tend to have better and more consistent average performance. This general relationship holds true for each of the scatter plots, but is most clearly seen in the plot for DOI score vs. schedule growth (Figure 4.5).

In section B of this chapter, where project performance was compared by project type, each of the alternative projects had some improvement over traditional projects, but not in every indicator. Here the relationship between DOI and project performance is consistent for each indicator. This indicates a direct connection between interaction and project performance.

1. User Satisfaction

Of the 38 projects with DOI information, 35 facility users provided usable questionnaires on their satisfaction. Table 4.3 also lists the results of the user satisfaction surveys. Users rated their satisfaction with project planning/design and project construction on a scale of 1-10. There was no significant difference between the two sets of ratings. Therefore, an average of the two ratings was calculated for each project and is used as an overall satisfaction rating.

Table 4.7 lists average user satisfaction by category. The average user satisfaction ratings are; for traditional projects 5.92, for partnered projects 7.62, for design-build projects 6.78, and for combination projects 8.50. Each of the alternative approaches has a

higher average user satisfaction than the traditional projects, with combination projects being the highest. The improvements in partnering and combination projects was statistically significant, as shown by the *p*- values. The variance for all three alternative approaches decreased, with combination projects having the lowest. Figure 4.8 shows these results graphically.

Table 4.7 Average User Satisfaction Ratings

Category	Average Satisfaction	Variance	*p* (T<=t) one tail
Traditional	5.92	6.34	-
Partnering	7.62	3.76	0.09
Design-Build	6.78	4.07	0.25
Combination	8.50	1.25	0.03

The results of the user satisfaction surveys were used to produce a scatter plot similar to those for DOI score vs. performance indicators. This plots DOI score against average user satisfaction (Figure 4.9). Although based on subjective input, this scatter plot has a pattern very similar to that of the plots for objective performance indicators above. User satisfaction with projects having low DOI scores varies considerably, while user satisfaction with projects having higher DOI scores tends to be higher and more consistent. User satisfaction appears to taper off slightly at the highest DOI scores.

2. Regression Analysis

Linear regression was used in an attempt to verify the observed relationship between DOI score and performance indicators, including user satisfaction. Linear

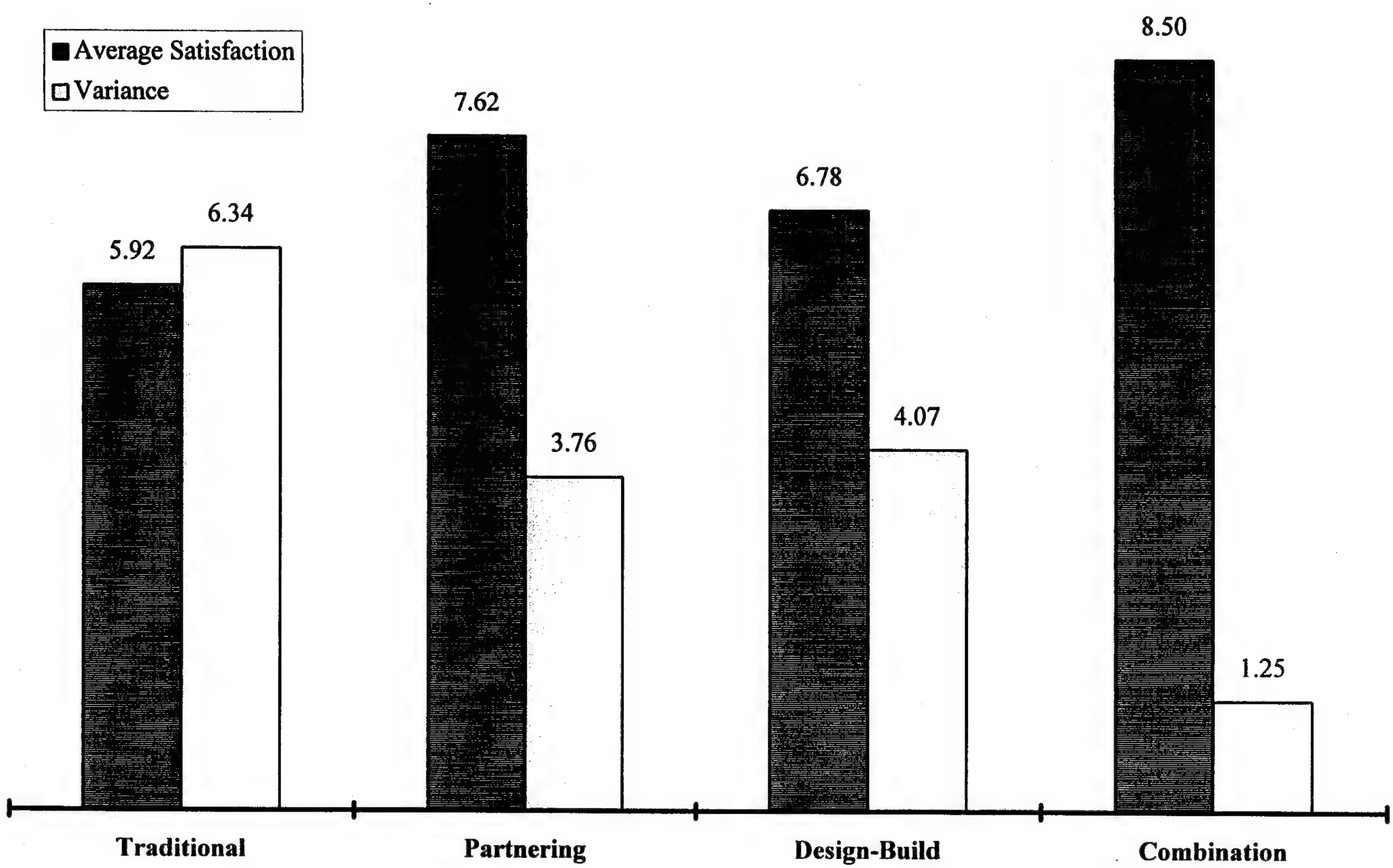

Figure 4.8 User Satisfaction Ratings by Category

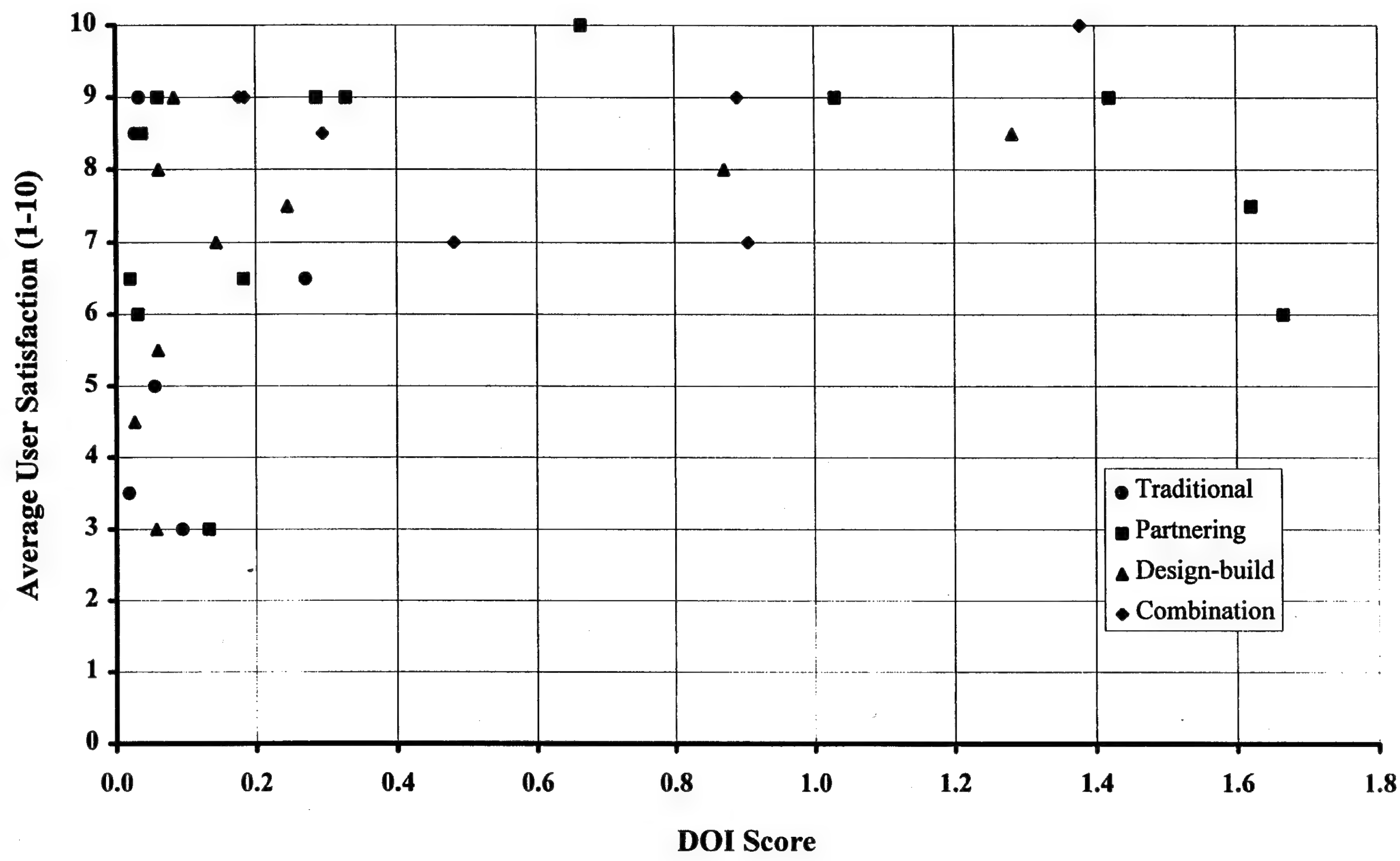

Figure 4.9 DOI Score vs. Average User Satisfaction

regression attempts to model the relationship with a straight line. It provides two statistics, r^2 , which is the fraction of the variance in the two variables that is shared, and a p-value, the probability that any apparent correlation is indeed non-existent. For example, if $r^2=0.59$, then 59% of the variance in X can be explained by (or goes along with) variation in Y.

As shown in Table 4.8, the correlation coefficients (r^2) are small for each potential relationship. Only schedule growth, number of modifications, and user satisfaction show modest correlation. In other words, a straight line does not serve as a good model for the relationship between DOI score and performance indicators. However, the p-values for schedule growth, number of modifications, and user satisfaction are quite small. These indicate that the modest correlation between DOI score and these indicators is significant.

Non-linear regression was investigated next to see if a curved line offered a better model for describing these relationships. Many different equation types were tried in looking for a good fit. Table 4.8 also shows the results of this exercise. For each performance indicator the table lists the highest r^2 and the type of equation used to achieve it. These results show a higher correlation than for linear regression, especially for schedule growth, design deficiencies, and user satisfaction. For these indicators, 20-25% of the change in performance is explained by increasing DOI scores. These r^2 values, while not large, clearly show that there is some sort of relationship between DOI score and these performance indicators. There are many factors affecting project performance, for example, weather, labor availability, site congestion, soil conditions, etc. Degree of interaction is only one factor, but it can diminish the negative impacts of other factors and enhance performance. However, this relationship, as observed in the scatter plots, is not best described by a straight or curved line model.

Table 4.8 Results of Linear and Non-linear Regression

Performance Indicators	**Linear Regression**		**Non-linear Regression**	
	$\mathbf{r^2}$	***p*-value**	**Equation Type**	$\mathbf{r^2}$
Cost Growth (%)	0.015	0.232	4th order polynomial	0.0489
Schedule Growth (%)	0.078	0.045	4th order polynomial	0.203
Modifications per Million $	0.058	0.072	power series	0.128
Modifications due to Design Deficiencies (%)	0.003	0.373	2 phase exponential decay	0.208
Average User Satisfaction (1-10)	0.106	0.028	4th order polynomial	0.244

3. "Threshold" Analysis

The relationship between DOI score and performance indicators (including user satisfaction) as shown in the scatter plots implies a "threshold" DOI score. Above this threshold, performance tends to be both better and more consistent. Also, performance does not continue to improve significantly beyond the threshold point. Examining the scatter plots, one can see that this threshold occurs at about 0.4 DOI. To verify this apparent result, projects were divided into two groups, those with DOI scores above and below 0.4. DOI scores 0.3 and 0.5 were also considered as possible thresholds, as listed in Table 4.9 below. There is only a small difference in results for the three possible threshold points. Comparing P-value, percent change in performance, and variance shows that results for 0.3 are slightly better than for 0.4, with 0.5 not as good. Because there are only three projects with DOI scores in this range, and to be conservative, 0.4 was chosen as the threshold value.

For each indicator, performance of the projects with higher DOI scores was improved. Based on the P-values listed in the table, this improvement was statistically

Table 4.9 Average Performance of Projects with DOI Scores Above and Below Possible Threshold Values

Performance Indicators	Performance			Variance			P (T<=t)
Threshold at DOI=0.3	DOI<0.3	DOI>0.3	% Change	DOI<0.3	DOI>0.3	% Change	one tail
Cost Growth (%)	8.96	6.55	-26.91	57.51	12.02	-79.09	0.0940
Schedule Growth (%)	31.89	12.00	-62.38	1315.91	183.26	-86.07	0.0102
Number of Modifications/ Million $	8.31	4.81	-42.12	50.65	7.83	-84.54	0.0189
Modifications Due to Design Deficiencies (%)	28.38	24.56	-13.48	673.40	371.64	-44.81	0.3168
Average User Satisfaction (1-10)	6.74	8.33	23.66	4.77	1.56	-67.28	0.0049
Threshold at DOI=0.4	DOI<0.4	DOI>0.4	% Change	DOI<0.4	DOI>0.4	% Change	
Cost Growth (%)	8.89	6.50	-26.85	55.34	13.09	-76.36	0.0960
Schedule Growth (%)	31.19	11.85	-62.00	1275.95	199.62	-84.35	0.0113
Number of Modifications/ Million $	8.43	4.26	-49.44	48.99	4.27	-91.28	0.0045
Modifications due to Design Deficiencies (%)	29.21	22.55	-22.79	656.43	355.78	-45.80	0.2031
Average User Satisfaction (1-10)	6.83	8.27	21.06	4.78	1.67	-65.03	0.0106
Threshold at DOI=0.5	DOI<0.5	DOI>0.5	% Change	DOI<0.5	DOI>0.5	% Change	
Cost Growth (%)	8.75	6.41	-26.74	51.52	15.89	-69.16	0.1084
Schedule Growth (%)	28.68	15.02	-47.62	1276.02	148.72	-88.34	0.0439
Number of Modifications/ Million $	8.05	4.51	-43.99	47.36	4.82	-89.82	0.0189
Modifications Due to Design Deficiencies (%)	28.01	24.28	-13.30	633.47	375.90	-40.66	0.3287
Average User Satisfaction Rating (1-10)	6.84	8.40	22.81	4.58	1.66	-63.83	0.0068

significant for every indicator except "Modifications due to design deficiencies." Variance also improved dramatically for each performance indicator. Average cost growth not only improved significantly for projects with DOI>0.4, but the variance was four times smaller. Average schedule growth was cut to less than half and its variance was only one sixth that of projects with DOI<0.4. The average number of modifications also fell by half and variance was ten times smaller. Design deficiencies fell on average, and the variance was reduced 46%. Finally, average user satisfaction improved 21% and variance fell by two thirds. Figure 4.10 shows these results graphically.

This approach of using a threshold DOI score to divide projects into two groups gives clear results. The difference in performance results is obvious and dramatic. This appears to be a more useful way to model the relationship between DOI score and performance than regression analysis.

4. Interaction Required to Achieve Threshold DOI Score

To get an idea of the interaction required to achieve such a DOI score, let us consider the first project in the sample to score above 0.4, "Phase I Apron / Hydrant." Interaction between designers and builders began in the detailed design phase for this project. 16 persons interacted an average of 40 hours per month each, during the 6 months of detailed design. Two other persons also participated in this interaction for 12 hours per month. During the construction phase, six persons each interacted for approximately 20 hours per month during the 20 months of construction. These same 6 persons also interacted 40 hours each during the one month start-up phase. The result of all this interaction was a DOI score of 0.481. The interaction for the "Maintenance Docks/Hangars" project, with a DOI score of 0.499, is detailed in Table 3.2. It included interaction in the planning, detailed design, procurement, construction and start-up phases.

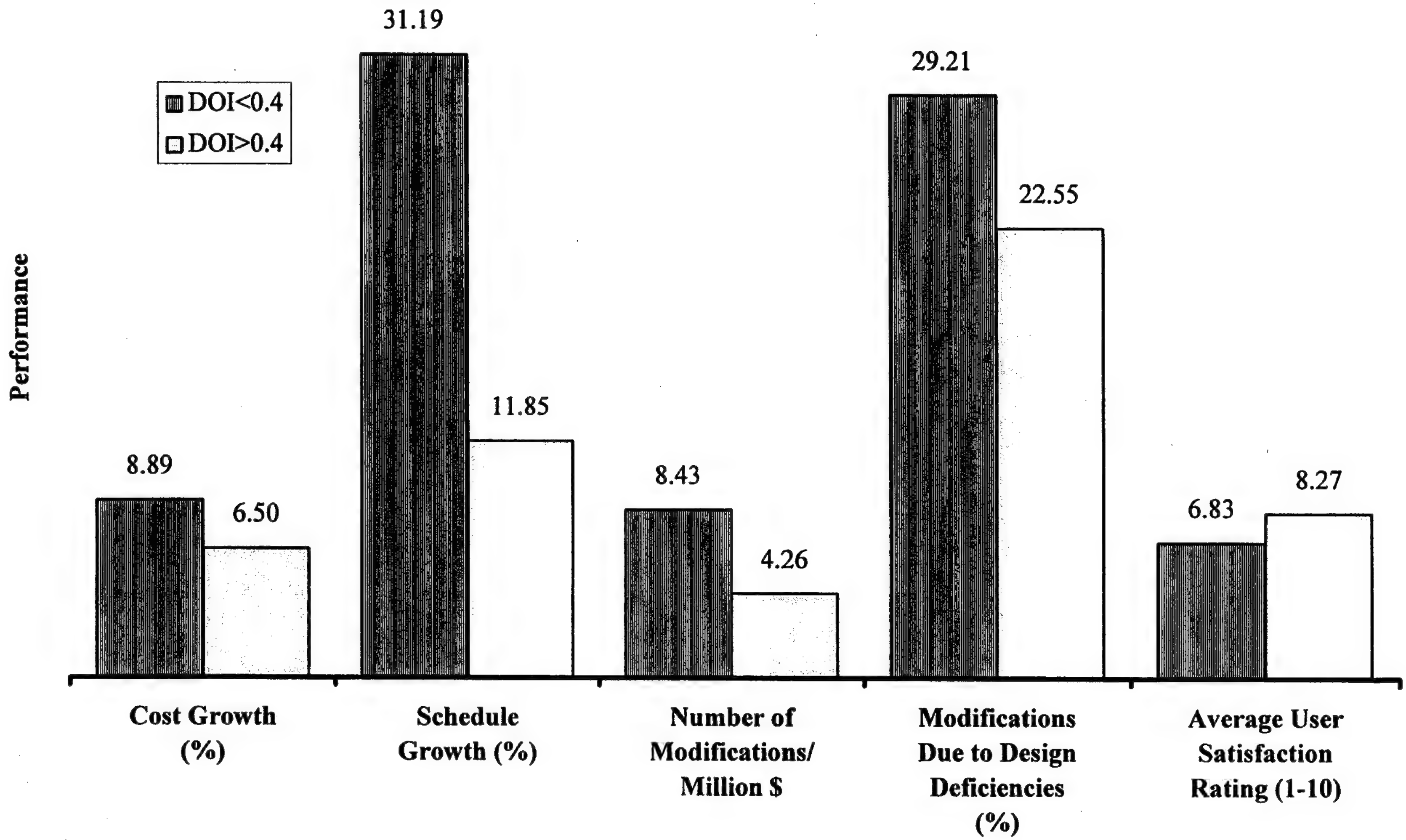

Figure 4.10 Comparison of Performance for Projects with DOI Scores Above and Below 0.4

Let us consider a hypothetical project with a five-month detailed design phase, a one-month procurement phase, and an 18-month construction phase. If a project team of 12 persons, including designers and builders, interacted two days a month during detailed design, one day during procurement, and one afternoon a week during construction, they would achieve a DOI score of 0.416. Without any interaction in the planning, conceptual design, or start-up phases, this project still earns a DOI score above 0.4. Table 4.10 shows how this is calculated. This is a relatively minor investment of time to reach a critical degree of interaction.

Table 4.10 DOI Score Calculation for a Hypothetical Project

Project Phases	**Weight Factor (P_k)**	**No. of Persons (m_k)**	**Interaction (hours/ month) (t_{ik})**	**Interaction Duration (months) (D_{ik})**	**Construction Duration (months) (*CD*)**	**DOI Score**
Planning	0.16	-	-	-	-	0
Conceptual Design	0.22	-	-	-	-	0
Detailed Design	0.25	12	16	5	18	0.083
Procurement	0.09	12	8	1	18	0.003
Construction	0.22	12	20	18	18	0.330
Start-Up	0.06	-	-	-	-	0
Total Score	1.00					0.416

But does the cost of additional interaction outweigh the potential benefits? In fact, the reduced cost growth for projects with DOI>0.4 is a net reduction, already including the cost of additional interaction. The difference in interaction between the hypothetical project above and one with a DOI score of only 0.2 is about 2700 manhours. This would cost approximately $81,000 at $30 per hour. However, most of the people interacting are already employed full-time on this project. For them, spending more time in interaction is

a question of time management and adds little, if any, real cost. The projects with DOI>0.4 absorbed this cost and still reduced average cost growth from 8.89% to 6.50%.

F. The Impact of Early Interaction on Project Performance

High DOI scores resulted not only from the amount of interaction, but also because some interaction occurred before the construction phase. This was true for nine of the twelve (75%) projects with DOI scores over 0.4. In fact, early interaction, regardless of DOI score, has an impact on performance. Nineteen of the projects had interaction before the procurement phase and nineteen did not. Table 4.11 lists the results when we compare the two groups of projects. The projects with early interaction had significantly less cost growth, fewer modifications, and design deficiencies. Even without achieving a DOI score of 0.4, early interaction still has a positive impact on performance. The differences in schedule growth and user satisfaction were not significant. Figure 4.11 shows these results graphically.

Table 4.11 Average Performance of Projects With and Without Early Interaction

Performance Indicators	Performance		Variance		*p* (T<=t)
	Without Early Interaction	With Early Interaction	Without Early Interaction	With Early Interaction	one tail
Cost Growth (%)	9.75	6.52	56.22	25.71	0.0646
Schedule Growth (%)	21.90	28.28	905.94	1137.34	0.2712
Modifications / Million $	8.37	5.86	64.01	11.25	0.1098
Modifications due to Design Deficiencies (%)	42.36	14.18	478.91	262.66	0.0002
Average User Satisfaction Rating (1-10)	7.21	7.36	4.25	4.35	0.4131

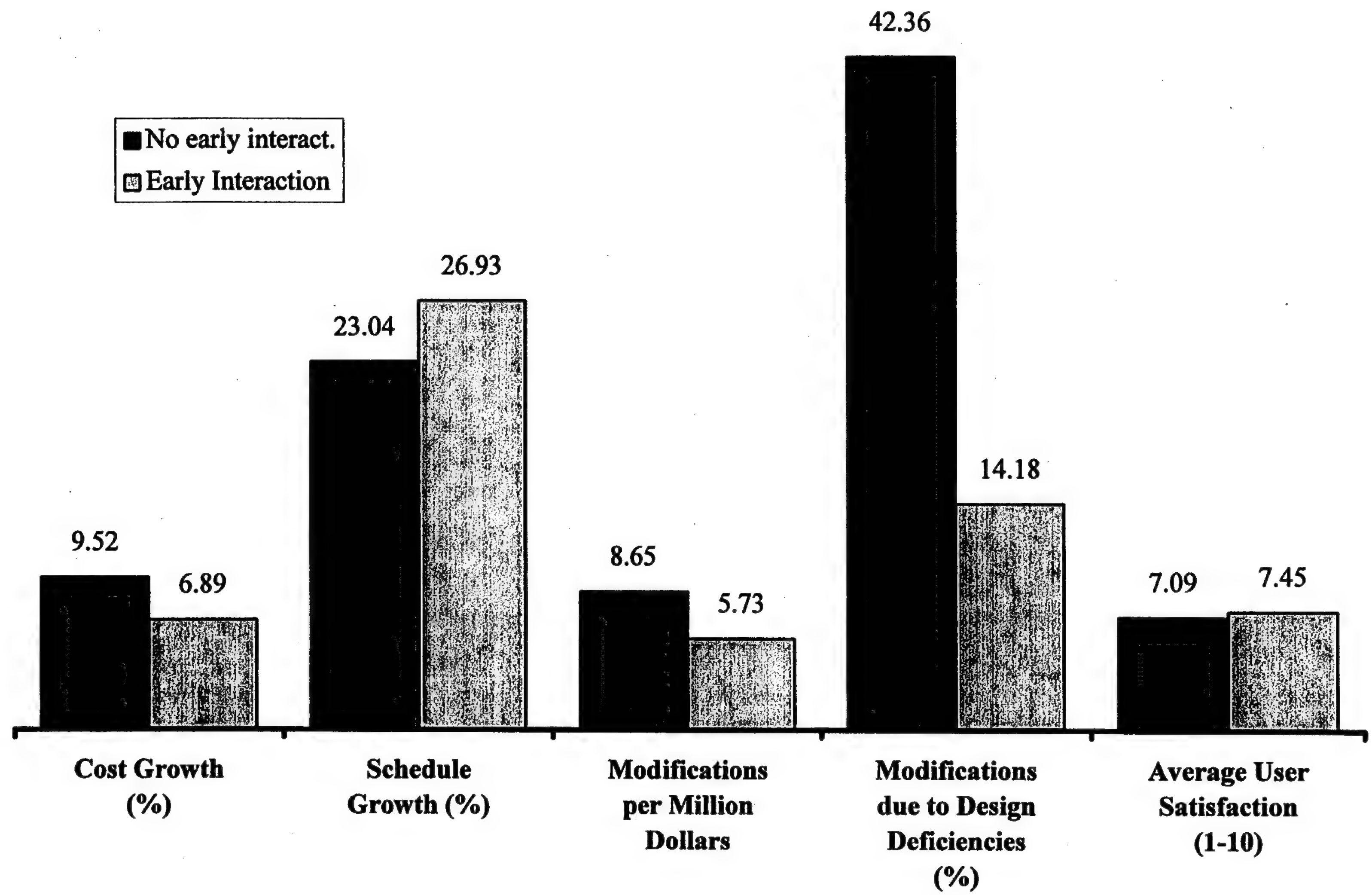

Figure 4.11 Average Performance of Projects With and Without Early Interaction

G. Using DOI Score to Predict Future Project Performance

Comparing the two groups of projects identified in "threshold" analysis can help predict performance of future projects. First we will compare the means and 95% confidence intervals of the two groups to see what kind of average performance can be expected in future projects. Next we will calculate the probability of improved performance in projects with DOI>0.4. Finally, examples are provided of the tangible savings that could be realized for these projects.

The difference in mean performance of the two groups points to substantial opportunities for improvement. For the projects with DOI>0.4, there was, on average, a 27% reduction in cost growth, a 62 % reduction in schedule growth, 49% fewer modifications per million dollars, 22% fewer modifications due to design deficiencies, and a 21% improvement in user satisfaction rating.

In addition to the observed average value of each performance indicator, statistical analysis gives us the 95% confidence interval for those averages. This means, that if we assume our sample is representative of the total population, we can be confident that 95% of the average performance of future projects will fall within this interval. This allows a decision maker to answer the question, "What sort of average performance can I expect if my projects achieve a DOI score>0.4?"

Figures 4.12 through 4.16 illustrate the different ranges of expected performance for projects with DOI scores above and below 0.4. Not only does the mean value of each performance indicator improve for projects with DOI>0.4, in each case but one, the range between upper and lower confidence intervals is reduced. The exception is for modifications due to design deficiencies, where the range in confidence intervals increases slightly (Figure 4.15).

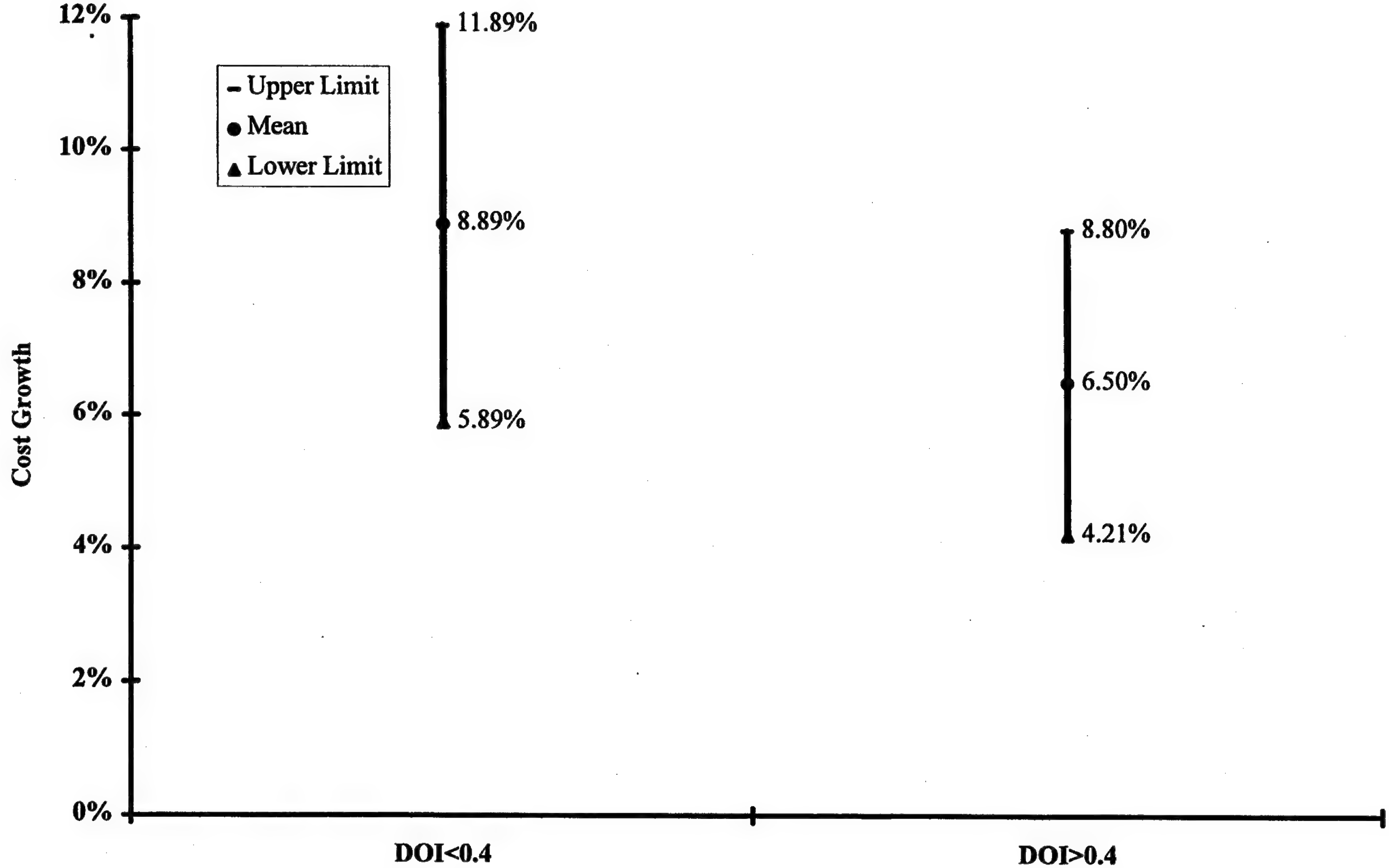

Figure 4.12 Predicted 95% Confidence Intervals for Average Cost Growth in Projects with DOI Scores Above and Below 0.4

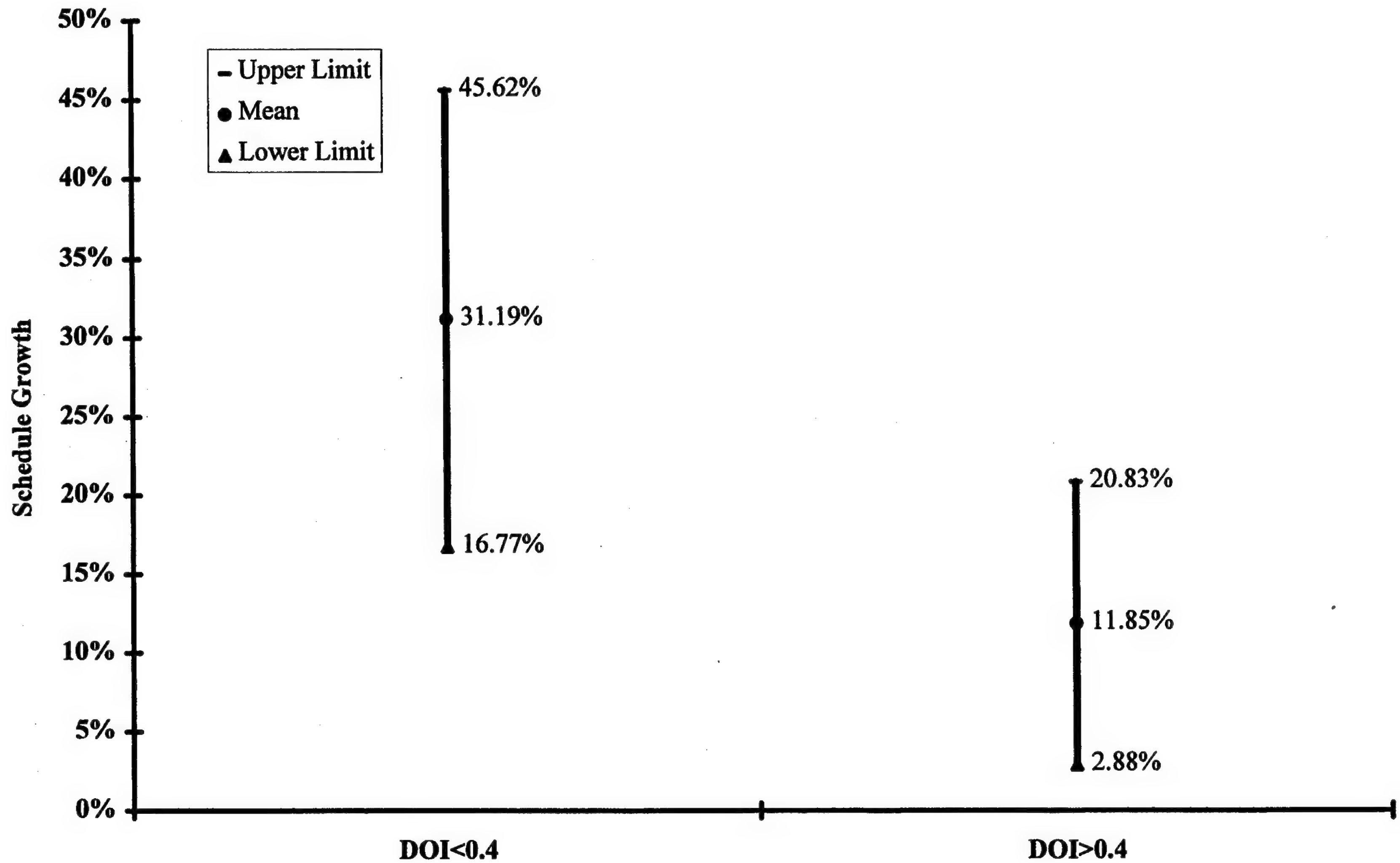

Figure 4.13 Predicted 95% Confidence Intervals for Average Schedule Growth in Projects with DOI Scores Above and Below 0.4

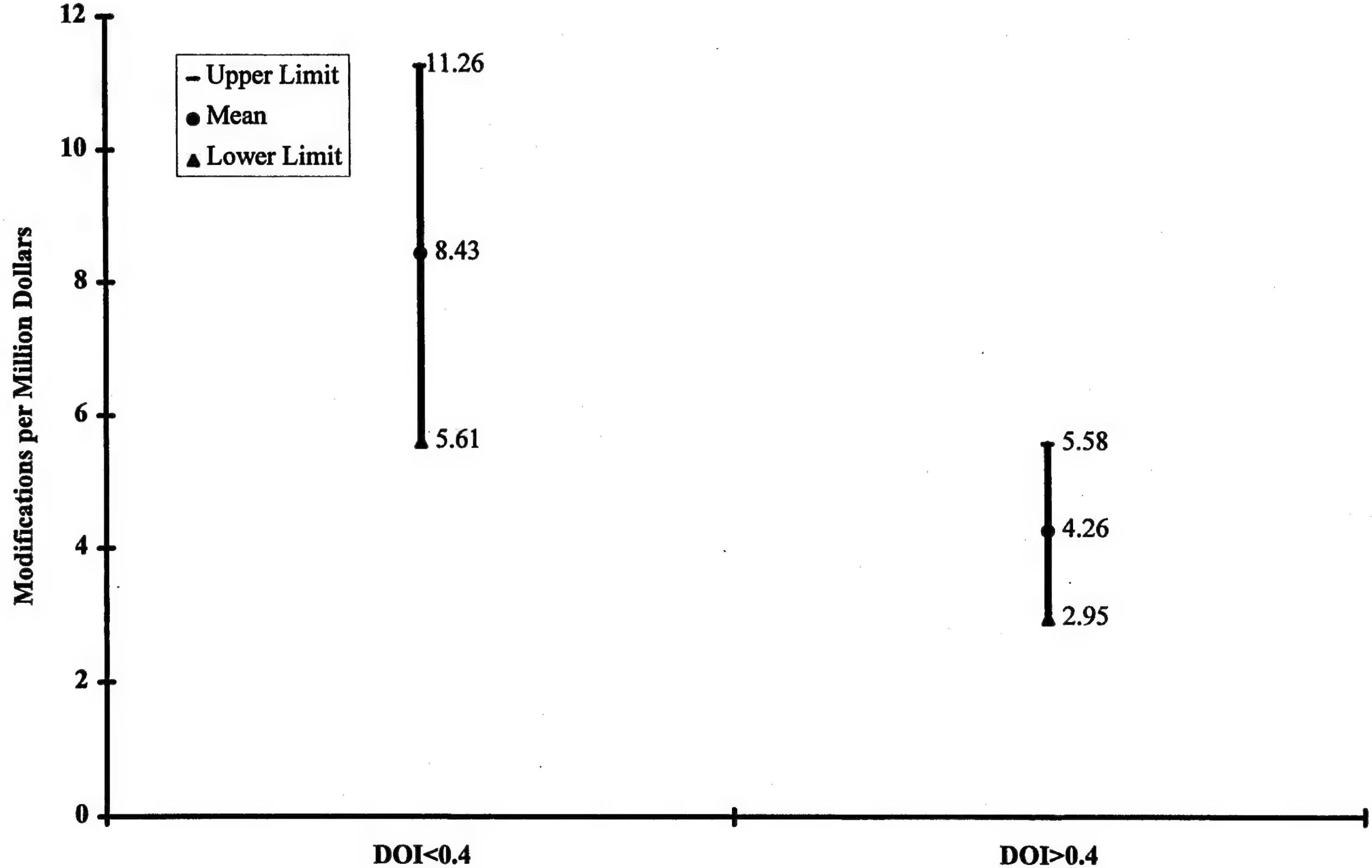

Figure 4.14 Predicted 95% Confirdence Intervals for Average Modifications in Projects with DOI Scores Above and Below 0.4

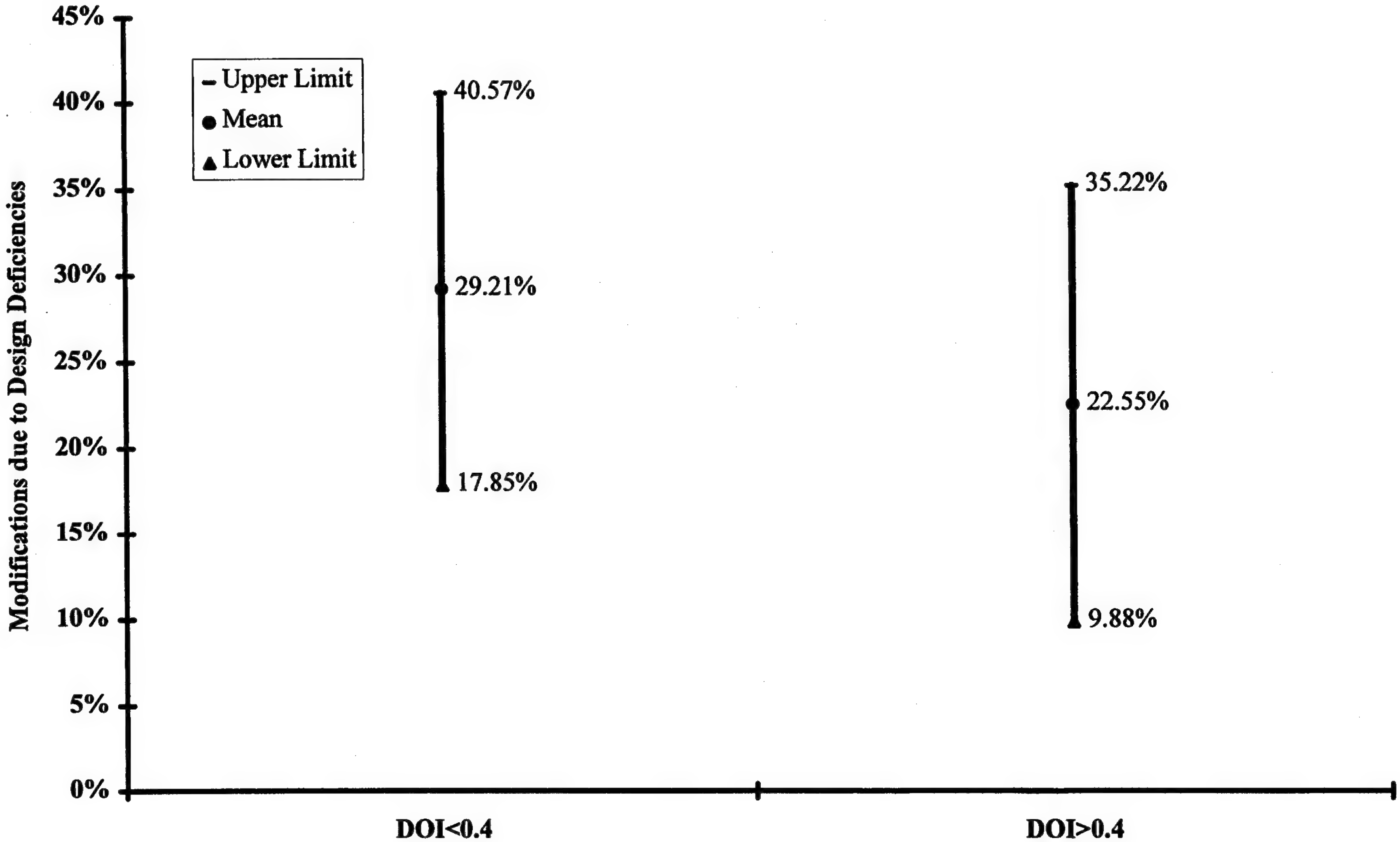

Figure 4.15 Predicted 95% Confidence Intervals for Average Design Deficiencies in Projects with DOI Scores Above and Below 0.4

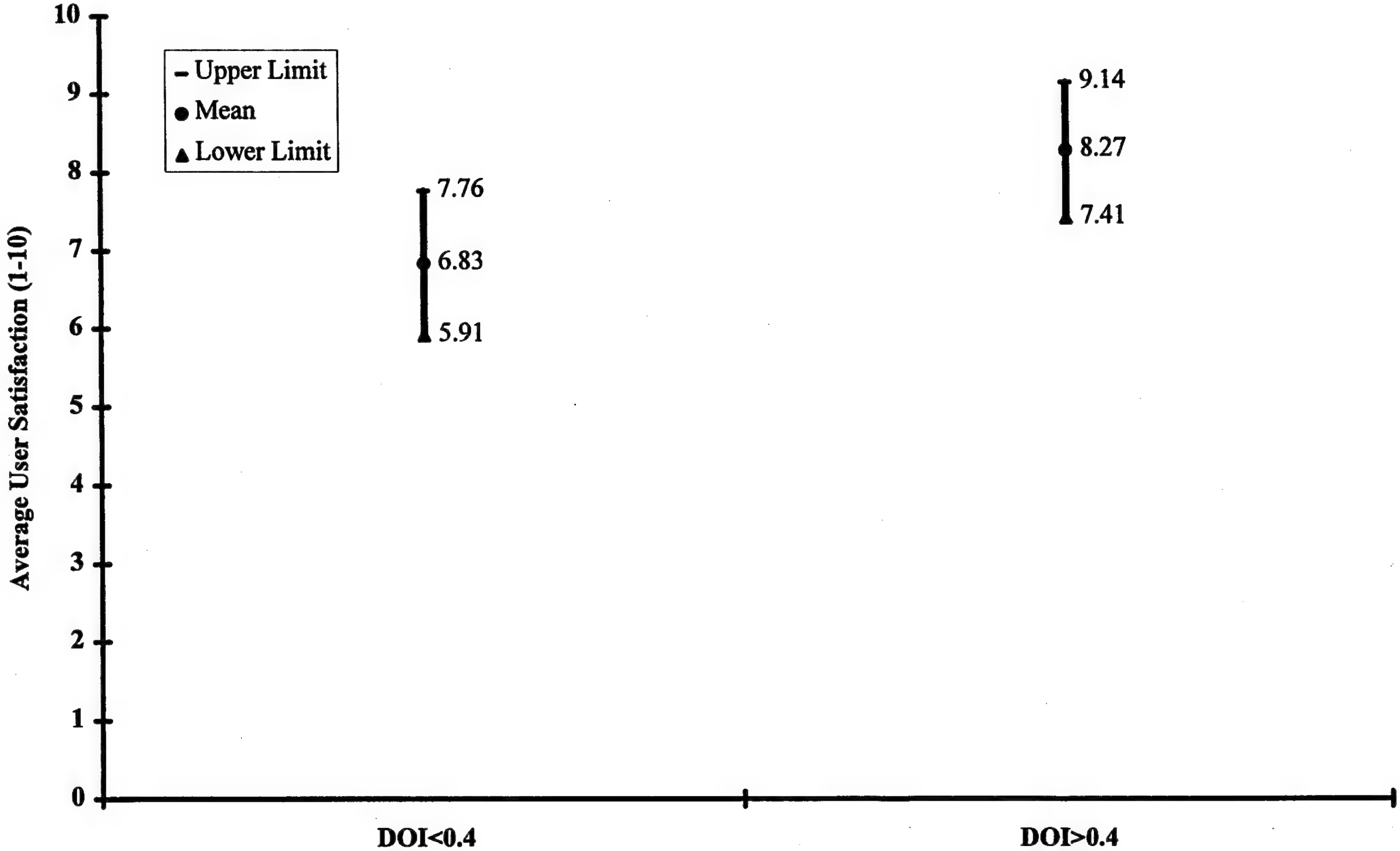

Figure 4.16 Predicted 95% Confidence Intervals for Average User Satisfaction in Projects with DOI Scores Above and Below 0.4

Another question a decision maker may ask is, "What is the probability that future projects with DOI>0.4 will have better average performance than projects with DOI<0.4?" This question can be answered using a probabilistic analysis involving the mean, standard error, and standard deviation of the two groups of projects (Ang and Tang, 1975). We begin with the average performance for each of the two groups. The probability of improved average performance is the same as the probability that the difference between the two means will be greater than zero. We can describe this difference in means by a distribution, assumed to be normal, with its own mean and variance. Assuming that the sample results are representative of the larger population of projects, we use the difference in means between the two groups as the expected mean of this distribution. Assuming the two groups of projects to be independent, we combine each group's standard deviation and standard error to estimate the variance of the distribution. We can assume the two groups of projects are independent because they are based on individual projects for different types of facilities, with different costs, locations, durations, and project teams. The above model allows us to calculate the probability of improved average performance for projects with DOI over 0.4 compared to those with lower DOI. See Appendix C for a more detailed discussion of calculating these probabilities.

For each of the performance indicators, the probability of improved average performance with DOI>0.4 over projects with DOI<0.4 is quite high. Modifications due to design deficiencies has an 80% chance of improving, cost growth 91%, and schedule growth, modifications per million dollars, and user satisfaction all have a 99% chance of improvement. These probabilities assume future projects are unlimited in number, and their respective performance indicators are normally distributed and independent.

While the average will govern for a large number of projects, due to the law of large numbers, the uncertainty with a single project is generally high. So what is the

probability that an individual project will experience improved performance with DOI>0.4? We can calculate this probability using essentially the same probabilistic analysis described above. The probability of improvement is 61% for cost growth, 69% for schedule growth, 71 % for modifications per million dollars, 58% for modifications due to design deficiencies, and 71% for user satisfaction. So even for an individual project with DOI>0.4, the probability of improvement over projects with DOI<0.4 is still quite high.

Now that we have established the probability of improved performance for both extremes, owners or contractors responsible for ten or twenty projects may want to know the probability of improved performance for their programs. Figure 4.17 shows the range of probabilities for each performance indicator. The probabilities of improved performance are given for one, ten, twenty, and an infinite number of projects.

Tangible Benefits

Finally, let us put the potential improvement in tangible terms. Consider a hypothetical government agency's relatively modest construction program of 20 projects averaging $5 million each, and totaling $100 million. If all the projects could achieve a DOI score of 0.4 or higher, and the improvement was consistent with the results of our sample, expected cost growth would decrease by $1.7 to $3.1 million. For a huge program on the scale of military construction (approximately $10 billion annually), the expected savings would be between $170 and $310 million. Using the same assumptions, the expected schedule growth on a project lasting 365 calendar days would be reduced between 50 and 90 days. Expected modifications would decrease between 2.66 to 5.68 per million dollars, or about 13 to 28 fewer modifications on a project of $5 million. Modifications due to design deficiencies would average only 23%, and average user satisfaction would rise by more than a full point on a scale of 1 to 10. Table 4.11 below

compares the predicted performance of two hypothetical projects with DOI scores above and below 0.4. Each project had an original cost of $5 million and an expected duration of 365 days.

Table 4.12 Predicted Performance of Hypothetical Projects
with DOI Scores Above and Below 0.4

Performance Indicators	DOI<0.4	DOI>0.4	Improvement
Cost Growth ($)	$444,500	$325,000	$119,500 (27%)
Schedule Growth (Days)	114	43	71 (62%)
Number of Modifications	42	21	21 (50%)
Modifications due to Design Deficiencies	12	5	7 (58%)
User Satisfaction (1-10)	6.83	8.27	1.44 (21%)

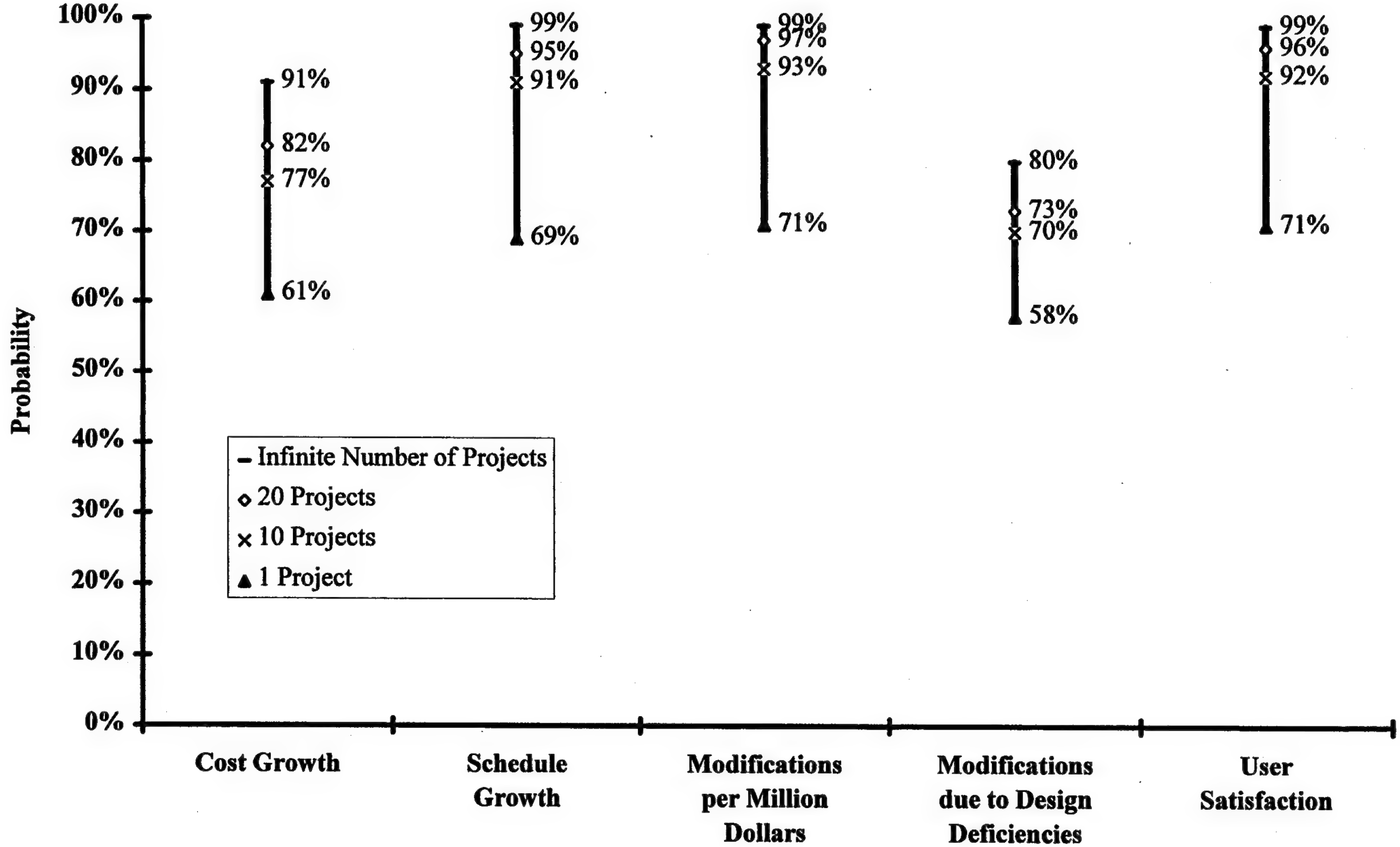

Figure 4.17 Probability of Improved Average Performance for Projects with DOI>0.4

CHAPTER V

CONCLUSIONS, CONTRIBUTIONS, AND FUTURE RESEARCH

The first objective of this research was to compare the performance of traditional projects to those using alternative approaches, to see if there were significant differences. I expected that the alternative approaches offered greater opportunities for integration, and should therefore have better performance. A second, and larger task, was to develop a method of measuring project integration and determine it's relationship to project performance.

The performance of 90 completed traditional construction projects was compared to 63 partnered, 40 design-build, and 16 combination projects. Performance was measured in objective terms by cost growth, schedule growth, modifications per million dollars, and modifications due to design deficiencies. A method was developed to measure interaction between designers and builders as an approximation of project integration. This "degree of interaction" (DOI) was measured for 38 of the 209 projects, including some from each category. DOI scores were then plotted against each of the objective performance indicators, as well as user satisfaction.

Alternative projects have significantly better average performance than traditional projects, as verified by *t*-tests. Scatter plots and regression analysis showed a modest but significant correlation between degree of interaction and project performance. Threshold analysis showed that projects with higher DOI scores clearly had better average performance than those with lower DOI scores. DOI scores can also be used to predict future average project performance.

These conclusions make contributions to knowledge in the field of construction engineering and management. There are also several possible avenues for future research

in this area. This chapter discusses these conclusions, contributions, and future research possibilities.

A. Conclusions

1. Projects Using Alternative Approaches Have Significantly Better Average Performance than Traditional Projects

Based on the 209 projects studied, each of the alternative approaches showed significantly better average performance for one or more of the four performance indicators. However, neither the partnering, design-build, or combination approaches was clearly "best". Each one was best for a different performance indicator. Selecting the most appropriate approach should depend on the specifics of the project.

Partnered projects had the lowest average schedule growth and were significantly better than traditional projects in number of modifications and design deficiencies. Partnered projects averaged less variance than traditional projects for every performance indicator. Design-build projects had the lowest average cost growth and design deficiencies of all approaches, and the variance for these two performance indicators was lower than for traditional projects. Combination projects had the fewest average modifications and were significantly better than traditional projects in every performance indicator except cost growth. Variance was less than traditional projects for each indicator except design deficiencies. Each alternative offers clear advantages over the traditional approach.

2. Alternative Projects Have Higher Average Degrees of Interaction than Traditional Projects

The degree of interaction methodology was used to calculate a DOI score for 38 of the 209 projects. DOI scores for traditional projects were clustered at the low end of the scale. They averaged 0.086 and the highest score in the category was only 0.27. This indicates there is very little opportunity for designer/builder interaction in the traditional design-bid-build approach.

The average DOI score for each of the alternative approaches is significantly higher than for traditional projects. Partnered projects have an average DOI score of 0.58, design-build projects average 0.31, and combination projects have the highest average DOI score at 0.60. This indicates that partnering, design-build, and combination projects offer opportunities for much more interaction between, designers, builders, and other project team members.

While they have higher average DOI scores, alternative approaches do not automatically guarantee higher DOI scores. The partnering, design-build, and combination categories all had a wide range of scores, including some projects with very low degrees of interaction.

3. Degree of Interaction Directly Impacts Project Performance

By comparing degree of interaction and performance indicators directly, regardless of project category, a relationship between the two is apparent. Performance tends to improve and be more consistent, for all indicators (including user satisfaction), as DOI scores increase. This indicates a direct relationship between degree of interaction and project performance.

Regression analysis shows a modest but significant correlation between DOI score and performance. Results of linear and non-linear regression show significant P-values for

schedule growth, modifications, and user satisfaction. Between 20% and 24% of the variance in these performance indicators can be explained by changes in degree of interaction.

Another way of examining the relationship between degree of interaction and project performance is to separate the sample projects into two groups. Most performance improvement occurs between 0.0 and about 0.4 DOI. Beyond a score of 0.4 DOI performance tends to level off and does not improve significantly.

Threshold analysis shows a clear difference in average performance between projects with DOI scores above and below 0.4. All but one indicator show significantly better average performance for projects with higher DOI, and variance is reduced dramatically for all indicators. In comparing projects with DOI less than 0.4 and greater than 0.4, cost growth drops from 8.89% to 6.5%, schedule growth falls from 31.19% to 11.85%, modifications decrease from 8.43% to 4.26%, design deficiencies are reduced from 29.21% to 22.55%, and user satisfaction rises from 6.83 to 8.27. The variance of each performance indicator decreased between 46% and 91% for the projects with higher DOI.

4. A Degree of Interaction Critical to Achieving Improved Project Performance Requires Only a Modest Investment in Integration

Since a DOI score of about 0.4 or greater has been shown to be a threshold value in improved performance, the interaction required to achieve this score was investigated. There are two conclusions. First, 75% of the projects with a DOI score above 0.4 had designer/builder interaction *before* the construction phase. Second, the interaction required to achieve 0.4 DOI is a relatively modest investment of time by the project team. A 12-person team, on a hypothetical project, interacting two days a month during detailed design, one day during procurement, and one afternoon a week during construction,

achieves a DOI score of 0.416. The potential benefits from this increased integration far outweigh the additional man-hour costs.

5. Early Interaction has a Positive Impact on Average Project Performance

Regardless of DOI score, if a project has early interaction (before the procurement phase) between designers and builders, there is an average improvement in performance. Half the projects studied had early interaction and half did not. Results from comparing the two groups show significantly better performance for cost growth, number of modifications, and design deficiencies. This verifies that the timing of interaction is an important element in improving project integration.

6. DOI Scores can be Used to Predict Future Project Performance

Based on statistical analysis of the sample results, future projects with DOI>0.4 should have better and more consistent performance than those with DOI<0.4. The average performance of projects with DOI>0.4 improved between 21% and 62% over projects with DOI<0.4, depending on the performance indicator. Not only is the average performance improved, but the 95% confidence interval range for predicted averages is smaller for all but one performance indicator, pointing to more consistent future average performance.

Using a probabilistic analysis of the mean, standard error, and standard deviation, the probability of improved average performance of future projects with DOI>0.4 over those with DOI<0.4 was calculated (see Appendix C). The probability of improvement was 91% for cost growth, 99% for schedule growth, 99% for modifications, 80% for design deficiencies, and 99% for user satisfaction. These probabilities assume an unlimited number of future projects. However, the probability of improvement is still strong for an individual future project. For a single project, the probability of improvement is 61% for

cost growth, 69% for schedule growth, 71% for modifications, 58% for design deficiencies, and 71% for user satisfaction. Obviously, the probability of improvement for other numbers of projects are to be found between these two ranges.

These strong probabilities of improved performance should lead decision makers to consider how they can ensure an adequate degree of interaction in future projects.

B. Contributions

1. A Quantitative Model for Assessing Alternative Approaches

Other researchers have used limited or subjective indicators to measure project performance. This research demonstrates a method relying on four objective measures (cost growth, schedule growth, modifications per million dollars, and percent modifications due to design deficiencies). These indicators could be measured for any project with complete records. A subjective measure, user satisfaction, was also included to verify the results of the other performance indicators. While not covering every aspect of project performance, this is a more comprehensive method than most studies have used.

2. Validating Improved Performance of Alternative Approaches Over Traditional Projects

Other researchers have compared relatively small numbers of one type of project (partnering for example) to traditional projects. Using 209 projects, this research objectively compares partnering, design-build, and combination (including constructability) projects to traditional projects. The results conclusively show that the alternative approaches each have significantly better performance in measured indicators than traditional projects.

3. Developing "Degree of Interaction" as an Indicator of Project Integration

Since integration cannot be directly measured, degree of interaction is presented as a useful surrogate measure of project integration based on the quantity of designer/builder interaction. By recording the hours spent in interaction by designers, builders, and other project team members, a DOI score can be calculated and compared with that of other projects. The DOI score calculated for each project is theoretically equivalent to the number of persons involved in full-time interaction through all project phases.

4. Verifying the Relationship Between Increased Interaction and Improved Performance

The consistent result for all performance indicators verifies the relationship between increased interaction and improved project performance. This relationship has long been accepted as "common sense" without being objectively validated. This relationship is characterized by having a relatively low threshold degree of interaction, beyond which performance is improved and more consistent.

5. Developing a Predictive Model of Project Performance Based on DOI

Statistical and probabilistic analysis allows us to predict with confidence that projects with a DOI>0.4 will have better and more consistent performance than those with DOI<0.4. Probabilities of improved performance were calculated for each performance indicator. This allows us to quantify expected performance improvements for a given construction program. These probabilities and predictions will help convince decision makers to provide opportunities for improved interaction in their projects.

C. Potential Applications of Research Results

Project managers, owners, government policy makers, and others interested in project performance can take advantage of these research results. Since projects with DOI>0.4 have a high probability of improved performance, decision makers will want to restructure their project environments to increase DOI scores. Using partnered, design-build, or combination projects will help provide the opportunity for increased interaction, but does not guarantee higher DOI or improved performance for individual projects. We know that achieving a DOI score above 0.4 does not take an unreasonable amount of people or time. What it does take is:

- putting the right people on the project team, including both designers and builders
- beginning interaction in the early project phases and spanning the design/construction interface, and
- building regular, planned interaction among all project team members into the normal way of doing business.

For the public sector, the biggest hurdle is how to get the builder involved before awarding the construction contract. Design-build is obviously one possible solution. Another is to use the Navy's example of inviting a shortlist of prequalified bidders to participate in the design process before competitive bidding. In an Army example, the Corps of Engineers hired a constructability consultant (CII) to gather builder input from interested bidders during design. Another option is to use in-house people with construction-phase experience from similar projects to fill the role of builder until the construction contract is awarded. The point is that there are a variety of ways to accomplish the interaction if the decision-makers are convinced of its value.

Appendix D is a worksheet for project executives and managers to use in predicting their project's degree of interaction and performance. It allows the manager to

estimate the DOI score they are likely to achieve and the resulting predicted performance. It also gives them an opportunity to adjust factors, such as the number of people or amount of interaction, to see the resulting change in DOI score.

D. Future Research

There are several possible directions for future research using this work as a point of departure. First, similar work could be done to validate my results and to standardize the methodology for measuring Degree of Interaction. This thesis attempts to measure project performance and project integration. There remains a need to more completely define and measure these two concepts. The heart of this direction of research is to identify and evaluate opportunities for improving project integration. Finally, researches should also demonstrate how to implement methods of improving integration.

1. Validating Results and Standardizing DOI Measurement

The most obvious need for future work in this area is to strengthen the conclusions of this research by increasing the number of projects with DOI scores available for analysis. This could be done in a number of ways. One way is to simply continue this work with additional projects. This approach could include several variations. Future research could use different performance indicators, revise the equation for calculating DOI, or adjust the phase weights. Analyzing DOI scores and performance of projects with very similar functions and scope would avoid comparing projects of different types.

A second approach would be to study a number of projects in progress so as to get more accurate measures of interaction, then compare predicted performance (based on DOI score) to actual performance.

2. Project Performance and Project Integration

Taking a step back from the immediate outcome of this research, let us consider the larger context. This work addresses two major areas of interest; project performance and project integration. Each offers a variety of opportunities for additional research.

Previous work and this research have attempted to define and measure project performance. There are a multitude of potential performance indicators, but only a relative few are commonly used. There is still a need for a standardized, comprehensive measure that includes objective components, such as cost and schedule performance, with subjective components such as owner/user satisfaction and project team attitudes.

Designer/builder interaction is only a portion of what constitutes project integration. Project integration remains largely a conceptual term. Despite work by others in this area, there is still a need to better define and measure project integration.

Even with the increased use of alternative approaches such as partnering, design-build, and constructability, there is still a great deal of room for improving project integration in the U.S. design and construction industry. Additional research into the legal/contractual, organizational, and social/psychological barriers to improved integration would be useful.

3. Improving Integration

Future research could continue to explore the technological and non-technological opportunities for improving integration. Technological opportunities include hardware and software that enable greater networking and real-time communication between project team members, as envisioned in concurrent engineering. Non-technological opportunities include new contracting and management approaches that allow, encourage, and even require interaction among team members, beginning at the earliest project stages.

4. Implementing Integration

As new methods for improving integration are developed, future research should also address implementation. Given the risky business climate of the construction industry, researchers will have to convince practitioners of the value of their ideas through demonstrated performance and thorough statistical analysis. Researchers also need to consider the impact their innovations will have on policy and decision making.

APPENDIX A

PROJECT LIST

CATEGORIES AND PROJECTS	COST GROWTH (%)	SCHEDULE GROWTH (%)	MODIFICATIONS PER $ MILLION	MODIFICATIONS FROM DESIGN DEFICIENCIES (%)
TRADITIONAL				
(Army) 1600M USARC-MCA/OMA	7.68	23.61	6.28	
Equipt. Maint. Facility	9.53	3.56	4.35	0.00
Harvil Renovation, Phase II	5.54	10.19	5.36	26.67
Tactical Equipment Facility	13.72	27.95	3.56	25.00
POL Storage Facility	2.56	47.11	1.21	
Child Support Center	2.54	0.00	2.51	
Parachute Packing Facility	7.04	33.33	4.64	
Freefall Simulator	9.29	16.85	5.12	
Academic Facility	3.89	54.09	3.49	
Group Ops Complex	5.22	129.44	6.32	
Company Ops II	2.40	46.67	3.71	
Sewage Treatment Facility	3.40	165.11	2.20	
Vehicle Maintenance Shop	12.41	51.58	4.23	
Airfield Pavement Repair	12.25	0.00	1.73	32.00
Child Development Center	2.62	29.81	2.89	64.71
Hangar TF160	0.44	18.54	3.33	45.45
Outdoor Athletic Facility	6.10	13.33	3.29	54.55
Helicopter Hangar	2.96	22.41	2.61	57.69
Unit Chapel	3.65	40.00	4.07	66.67
Youth Activity Center	0.94	13.52	4.86	61.54
Applied Instruction Building	7.98	19.17	2.25	86.67
Water Storage Tank	1.69	-9.58	2.21	
Porter Road Bridge	12.79	27.22	7.29	27.27
Tank Driver Facility	5.85	25.94	6.62	40.63
Arts and Crafts Center	12.24	65.71	13.90	55.26
Youth Center	6.48	67.11	10.34	61.54
Child Support Center	4.59	-9.32	11.20	25.00
Child Support Center	5.41	11.69	7.65	28.57
Child Development Center	3.81	34.33	14.69	33.33
Hazardous Waste Facility	103.92	47.53	6.20	
Hazardous Landfill	21.00	26.45	2.92	68.49
Ammunition Workshop	8.90	46.30	9.14	
(AF) Composite Medical Facility	11.27	42.09	9.17	
Squadron Operations Facility	4.57	10.59	6.37	
Taxiway, Aprons, Lighting	-0.99	63.33	6.13	13.33
Aircraft Maintenance Dock	6.46	11.67	4.09	
Aircraft Fuel System Dock	4.00	19.39	10.12	50.00
Flight Simulator Facility	2.67	-9.44	19.48	35.00
Shortfield Assault Strip	25.50	21.48	5.17	45.45

Add/Alter Field Training Facility	24.72	103.33	14.66	74.19
Engine Inspection & Repair Facility	21.39	74.44	28.65	65.00
Vehicle Operations Facility	8.48	0.55	9.20	30.00
Gymnasium	3.65	18.52	8.18	
Alternate Taxiways	25.28	125.83	7.24	
Religious Education Facility	1.50	4.60	11.08	40.00
Child Development Center	4.39	3.25	6.71	34.48
Missle Inspection Facility	8.19	22.22	8.16	54.55
Enlisted Dormitory Alteration	2.44	2.78	6.11	
Test Facility	13.16	19.00	8.74	
Enlisted Dormitory Ateration 89	5.37	13.75	10.19	
Add/Alter Child Development Ctr.	5.18	40.00	27.64	30.43
Munitions Storage Complex	3.81	1.78	4.51	
Consolidated Support Center	8.34	25.93	7.05	40.00
Child Development Center	6.74	15.11	13.18	26.32
Dormitory	2.39	41.33	5.28	30.77
Child Development Center	6.70	63.94	13.17	32.56
Child Care Center	2.10	13.06	12.08	32.35
Add/Alter Weapons Support Fac.	20.58	50.17	2.69	35.14
Aircraft Corrosion Control Facility	8.22	20.74	2.45	78.13
Depot Aircraft Hangar	4.71	2.08	2.34	44.83
C-141 Maintenance Hangars	5.02	15.06	1.01	47.62
Medical Training Facility, Phase 1	11.65	32.17	8.10	
Add to Wing Headquarters	2.08	16.04	10.97	
Weapons Systems Training Facility	6.15	29.78	15.25	16.67
Alter Technical Training Facility	7.51	-14.81	13.97	33.33
Wing Operations Facility	3.71	10.29	16.91	26.47
Add to Aircraft Systems Training	5.19	-2.20	5.17	5.00
Airmen Dining Hall	3.93	3.67	13.92	
Flight Simulator Facility	8.54	60.12	24.22	
Add/Alter Electric Substation	2.27	18.09	11.10	7.69
Child Development Center	11.00	26.94	30.53	42.03
Child Development Center	1.76	-1.79	18.54	26.67
Field Training Detachment	7.53	35.62	5.55	42.03
Radar Approach Control Facility	4.00	10.91	17.54	50.00
Upgrade Utilities	14.53	-7.17	6.69	68.48
Helicopter Hangar	13.57	10.00	14.08	28.85
Alter Maintenance Hangar	5.11	24.89	5.14	67.11
Maintenance Management Facility	3.28	-12.89	8.27	53.33
Visiting Officers' Quarters/ TLF	3.57	7.45	5.83	49.12
Control Tower	4.40	124.67	12.00	42.42
Security Lighting & Fencing	14.11	31.43	13.39	30.91
Fuel Cell/ Corrosion Control Floors	0.00	-3.33	4.30	20.00
Foreign Material Facility	2.43	1.28	4.98	70.83
Child Development Center	5.42	23.56	8.40	31.25
Special Intelligence Facility	17.03	2.86	5.93	54.76
(Navy) Aircraft Rapid Refuel Station	27.36	13.99	6.97	59.52
Aircraft Maintenance Hangar	2.87	0.00	1.87	38.46
Bachelor Enlisted Quarters	5.07	20.65	4.71	50.00
Naval Intelligence Center, Phase I	2.19	0.00	4.57	

Hazardous Waste Storage Facility	12.56	100.37	6.72	20.00
Category Average	**8.48**	**27.76**	**8.30**	**41.84**
PARTNERING				
(Army) Recreation Center, Sand Hill	4.33	17.26	1.60	
Conv. General Instruction	8.72	5.91	2.70	
Aviation Maintenance Hangar	10.86	18.89	2.74	
IMMD INFRA/OOL	15.64	-17.56	1.48	8.70
Vehicle Maintenance Facility	5.44	3.74	3.89	28.89
Family Practice Clinic	2.52	19.25	10.74	
Soldier Service Center	16.10	25.67	4.87	19.51
Sattelite Communications II	2.25	5.62	3.90	
Building Renovation, USAREC	10.03	6.02	18.00	60.78
HQ US Army Reserve Facility	13.52	62.08	3.15	47.22
Sewage Treatment Plant	2.11	6.51	2.38	34.38
(AF) J-6 Rocket Test Facility	6.13	11.69		39.53
Child Development Center	0.76	0.33	6.25	30.00
Small Aircraft Maintenance Dock	1.72	5.00	7.15	54.55
Weapons Release Facility	3.22	2.67	7.14	
Inspection & Repair Facility	2.21	7.67	7.99	33.33
200 Person Dormitory	2.56	5.00	5.72	54.55
Corrosion Control Facility	7.53	86.33	8.09	22.73
Child Development Center	1.07	9.26	10.63	25.00
HQ AF Inspectcion & Safety Center	14.69	-7.50	8.63	43.27
AAVS Service Center and HQ	7.45	13.70	5.81	55.26
Child Development Center	4.35	15.75	17.27	41.07
Base Supply Support Center	5.75	9.33	2.34	25.00
Dormitories/Dining Hall	17.17	5.59	8.62	35.52
Aircraft Maintenance Shop	4.52	23.45	3.96	48.57
Corrosion Control Facility	3.41	19.44	10.36	13.64
Enlisted Dormitory	5.56	10.35	4.29	35.00
Engine/Metals Training	6.48	-6.67	9.09	39.42
Air Ground Equipment Training	3.77	16.67	8.25	40.00
Dining Facility	4.27	14.05	8.34	24.24
B-2 Avionics Facility	9.60	16.27	4.21	12.12
Educational Facility, AFIT	7.27	32.22	9.84	68.33
Addition to Avionics Lab	8.51	15.00	9.73	54.41
Hazardous Materials Storage Facility	2.33	16.88	5.24	37.93
Acquisition Management Complex	8.32	31.83	5.86	39.05
Rehab Building 32	5.54	12.34	12.45	46.15
Taxiway	10.70	18.04	2.83	50.00
(Navy) Hospital/Dental Clinic Replacement	6.17	23.52	6.25	
Armory	1.29	0.00	3.46	50.00
Bachelor Enlisted Quarters	1.60	-5.26	5.45	
Landing Craft Complex, Ph. 3&4	15.87	42.88	5.06	44.71
Urban Training Facility	14.42	-26.16	3.19	
Wastewater Treatment Plant	4.16	79.73	2.27	39.02
Air Control Ops Facility	3.86	5.36	1.97	20.00
Fleet Headquarters Facility	7.11	13.74	11.40	46.60
Explosives Handling Warf	5.14	6.91	2.01	38.75

LCAC Phase III	2.91	11.30	5.34	32.35
Air Traffic Control Facility	18.21	9.92	10.69	
Top Gun Facility	31.70	43.91	29.12	
Child Development Center	28.90	34.29	22.72	
CASS Training Building	7.75	0.00	5.68	
Industrial Waste Treatment Plant	0.54	9.19	5.66	
Water Distribution System	9.75	38.74	2.60	
Drydock Modernization	13.92	1.28	3.27	
Replacement Hospital, Phase II	18.62	14.93		
North Bay Medical Clinic	5.00	23.03	6.56	
Bachelor Enlisted Quarters	12.83	24.71	7.17	47.73
Secure Assembly/Test Facility	20.11	-7.43	10.01	
Electrical Distribution System	2.51	-15.61	2.24	
Utilities	11.20	102.78	3.19	
Site Improvements	23.49	77.78	4.50	
Naval Intelligence Center, Phase II	28.52	18.75	10.26	
Naval Intelligence Center, Phase III	1.17	8.33	3.85	
Category Average	**8.62**	**17.06**	**6.88**	**38.14**
DESIGN-BUILD				
(Army) Golf Course	2.81	21.81	3.66	4.17
Guest House	5.52	-22.22	1.76	0.00
Enlisted Club	9.74	12.96	2.74	0.00
Youth Activity Center	-0.38	17.78	3.85	0.00
Auto Craft Center Addition	4.69	84.87	9.95	0.00
Golf Course Expansion	1.28	-44.44	3.16	10.00
NCO Club	1.89	21.64	2.60	0.00
NCO/ Enlisted Club	1.08	43.87	5.13	0.00
CID Command Field Office Building	7.66	6.67	9.07	5.00
Golf Course and Clubhouse	8.26	24.66	2.96	12.50
Child Development Center	1.02	0.00	3.57	18.18
Child Development Center	6.39	134.52	13.86	49.33
Indoor Swimming Pool	0.98	17.38	6.59	6.67
Golf Course Clubhouse	10.54	44.05	5.30	0.00
Commissary	36.55	59.44	5.83	11.11
Commissary	3.93	16.48	1.41	0.00
(AF) Field Training Detachment Fac.	5.20	-5.58	3.53	7.14
Cryptologic Support Center	31.73	0.74		
Medical Clinic	2.94	5.38	2.35	33.33
DLI Dining Facility	1.45	81.25	7.51	9.09
DLI Student Enlisted Housing	3.85	81.25	4.69	8.51
DLI Student Officer Housing	4.15	12.35	2.80	
Replace Main Substation	-0.03	12.00	5.35	0.00
Child Development Center	7.80	37.87	31.80	12.50
Health Care Facility	11.68	15.77	5.42	35.96
Education Center	0.25	5.14	4.68	0.00
War Reserve Material Warehouse	4.13	10.00	7.13	0.00
Student Enlisted Dorms	3.04	7.65		
B-1 Avionics Facility	7.01	48.88	5.46	
Whole Blood Facility	5.29	15.60	4.06	
(Navy) Water Storage Tanks	2.62	8.70		

Family Services Center	4.64	-2.19	8.21	
Child Development Center	5.91	-12.53	18.16	
Child Development Center	-0.51	73.89	15.51	13.33
Child Development Center	0.19			
Centrifuge Trainer	11.72			
Bachelor Enlisted Quarters	2.57	7.41	1.51	16.67
Child Development Center	5.15	16.67	14.69	
Child Development Center	18.44	33.65	9.43	
Parking Structure	13.46	103.22	4.35	
Category Average	**6.37**	**26.23**	**6.80**	**9.39**
COMBINATION				
(Army) Sparkman Center	4.30	18.46	1.26	4.11
Commissary Renovation	10.59	63.56	8.17	6.06
Special Purpose Facility	1.56	16.39	0.78	0.00
General Education Development Ctr.	6.00	5.96	3.72	0.00
Consolidated Support	5.34	17.23	3.36	1.59
(AF) Add/Alter Hydrant System	6.49	-15.28	4.92	28.95
Child Development Center	3.71	5.78	7.06	3.33
Underground Storage Tanks	18.22	20.56	7.28	36.36
Maintenance Docks & Hangars	7.43	7.30	3.18	0.58
Composite Medical Facility	20.33	-11.14	3.12	66.02
Add/Alter Library	41.20	32.78	7.08	20.00
Child Development Center	7.36	65.67	7.33	11.76
Upgrade Industrial Waste Treatment	1.15	11.54	1.24	0.00
Four Season Store	9.60	16.27	4.21	12.12
(Navy) Propulsion Training Facility	6.19	45.96	7.11	25.21
Shore Intermediate Maintenance Act.	17.51	-0.82	9.42	26.80
Category Average	**10.44**	**18.76**	**4.95**	**15.18**

APPENDIX B

SURVEYS

<u>**FACILITY SATISFACTION SURVEY**</u>

Instructions:
As someone familiar with this facility, please answer the following questions.

Your Name: ________________ **Your Title** ________________________

Facility/Project: ______________ **Location:** _________________________

1. What is your satisfaction with the facility's planning/design?

1	2	3	4	5	6	7	8	9	10
very low				neutral					very high

2. Given the design, what is your satisfaction with the constructed facility?

1	2	3	4	5	6	7	8	9	10
very low				neutral					very high

3. How well does this facility meet your need?

1	2	3	4	5	6	7	8	9	10
very poorly				adequate					very well

4. If this facility did not meet your needs, was it because of inadequate design or construction?

5. Comments:

Thank You for your assistance!

WEIGHTING THE VALUE OF INTERACTION IN PROJECT PHASES

As part of my thesis research I am trying to measure the importance of interaction between designers and builders to project success. In order to produce an interaction score for individual projects, I want to weight the relative value of interaction in each project phase.

INSTRUCTIONS: In the spaces below, show what you believe is the relative value of interaction in each project phase, as a percent of the total. The values for each phase should total 100%.

Project Phase	Value of interaction in this phase	Example
Planning	____%	35%
Conceptual Design	____%	27%
Detailed Design	____%	18%
Procurement	____%	11%
Construction	____%	7%
Start-up	____%	2%
	100%	100%

Thank you for your assistance! Please return this form to me at the fax number or address above.

QUESTIONNAIRE FOR MEASURING PROJECT INTERACTION

This questionnaire attempts to measure the degree of integration in terms of **INTERACTION BETWEEN DESIGNERS AND BUILDERS.**

YOUR NAME:_______________ **PROJECT NAME:**_______________________
PHONE #: _______________

I. INSTRUCTIONS:

Interaction Phase: Enter data for each phase in which designers and builders had direct contact.

1) Number of Persons: How many persons were involved in each phase of interaction?
2) Job Titles: Give the job titles for each person involved in the interaction. Be specific (e.g., project architect, contractor's project manager, etc.).
3) Hours/Month: Approximately how many hours per month did each person spend in interaction?
4) Duration: How many months did interaction occur during this phase?
5) Misc. Cost: What miscellaneous costs were associated with interaction (e.g., telephone calls, travel, and office expenses)?
6) Interaction Type: Was the interaction by planned schedule or in reaction to problems?

Interaction Phase	1)Number of Persons	2) Job Titles	3) Hours/ Month	4) Duration (months)	5) Misc. Cost ($)	6) Interaction Type (problem or scheduled)
Planning						
Conceptual Design						
Detailed Design						
Procurement						
Construction						
Start-up						

II. CONTENT

Please describe the most common content of the interaction between designers and builders on this project:

III. REMARKS

Is there anything out of the ordinary we should know about this project?

THANK YOU FOR YOUR TIME AND COOPERATION IN FILLING OUT THIS QUESTIONNAIRE!

APPENDIX C

CALCULATING PROBABILITY OF FUTURE AVERAGE PERFORMANCE

We would like to know the probability of improved performance for projects with DOI>0.4 over those with DOI<0.4. We begin by comparing the two groups of projects:

w_i = Performance of the ith project (DOI>0.4)

X_n = Average performance for n projects (DOI>0.4) = $\frac{1}{n}(w_1+w_2+\ldots+w_n)$

z_i = Performance of the ith project (DOI<0.4)

Y_n = Average performance for n projects (DOI<0.4) = $\frac{1}{n}(z_1+z_2+\ldots+z_n)$

n = Number of future projects

On the basis of the observed performance data, normal distributions may be assumed for w_i and z_i with means μ_w, μ_z and standard deviations σ_w, σ_z respectively. Given this model, the probability of improved average performance of projects with DOI>0.4 over those with DOI<0.4 is:

$$P(X_n < Y_n) = P(X_n - Y_n < 0)$$

(For user satisfaction, $P(X_n > Y_n) = P(X_n - Y_n > 0)$).

We can define $X_n - Y_n$ as B which is also a normal random variable with mean

$$\mu_B = \mu_{X_n} - \mu_{Y_n} = \mu_w - \mu_z$$

and standard deviation

$$\sigma_B = \sqrt{Var(X_n) + Var(Y_n)}$$

We do not include a term for covariance since we assume the two groups of projects are independent and covariance would be zero.

In assessing these mean values and variances from the observed data, we can estimate μ_w by the observed average values of w, that is $\bar{w}$. Error could exist in this estimate because of the limited number of observations. The error in μ_w is described by its standard error $\sigma_{\bar{w}}$ which is $\frac{\sigma_w}{\sqrt{m}}$, where m is the number of observations.

It can be shown that

$$Var(X_n) = \frac{\sigma_w^2}{n} + \sigma_{\bar{w}}^2$$

This first term denotes the total contributions of the variability of each w_i whereas the second term denotes the contribution resulting from the error in estimationg the μ_w. The value of σ_w can be estimated by the sample standard deviations of the observed values of w, that is s_w. The same derivation can be performed for μ_z and $Var(Y_n)$.

Finally, we have

$$\mu_B = \bar{w} - \bar{z}$$

and

$$\sigma B = \sqrt{\frac{S_W^2}{n} + \sigma_w^2 + \frac{S_Z^2}{n} + \sigma_z^2}$$

and

$$P(Xn - Yn < 0) = \Phi(-\frac{\mu B}{\sigma B})$$

where $\Phi(\ )$ is the cumulative distribution function of a standard normal random variable.

Cost Growth

$\bar{z} - \bar{w} = 2.39$, standard deviation $z = 7.44$, standard error $\bar{z} = 1.46$,
standard deviation $w = 3.62$, standard error $\bar{w} = 1.04$
1 Project: P = $\Phi(2.39/8.46) = \Phi(0.28) = 61\%$
10 Projects: P = $\Phi(2.39/3.17) = \Phi(0.75) = 77\%$
20 Projects: P = $\Phi(2.39/2.58) = \Phi(0.92) = 82\%$
Infinite Projects = $\Phi(2.39/1.79) = \Phi(1.33) = 91\%$

Schedule Growth

$\bar{z} - \bar{w} = 20.05$, standard deviation $z = 35.72$, standard error $\bar{z} = 7.01$,
standard deviation $w = 14.13$, standard error $\bar{w} = 4.08$
1 Project: P = $\Phi(20.05/39.26) = \Phi(0.51) = 69\%$
10 Projects: P = $\Phi(20.05/14.60) = \Phi(1.37) = 91\%$
20 Projects: P = $\Phi(20.05/11.81) = \Phi(1.70) = 95\%$
Infinite Projects = $\Phi(20.05/8.11) = \Phi(2.47) = 99\%$

Modifications

$\bar{z} - \bar{w} = 4.17$, standard deviation $z = 6.70$, standard error $\bar{z} = 1.37$,
standard deviation $w = 2.07$, standard error $\bar{w} = 0.60$
1 Project: P = $\Phi(4.17/7.45) = \Phi(0.55) = 71\%$
10 Projects: P = $\Phi(4.17/2.75) = \Phi(1.52) = 93\%$
20 Projects: P = $\Phi(4.17/2.20) = \Phi(1.88) = 97\%$
Infinite Projects = $\Phi(4.17/1.50) = \Phi(2.78) = 99\%$

Design Deficiencies

$\bar{z} - \bar{w} = 6.66$, standard deviation $z = 25.62$, standard error $\bar{z} = 5.46$,
standard deviation $w = 18.86$, standard error $\bar{w} = 5.69$
1 Project: P = $\Phi(6.66/32.77) = \Phi(0.20) = 58\%$
10 Projects: P = $\Phi(6.66/12.78) = \Phi(0.52) = 70\%$
20 Projects: P = $\Phi(6.66/10.62) = \Phi(0.63) = 73\%$
Infinite Projects = $\Phi(6.66/7.88) = \Phi(0.85) = 99\%$

User Satisfaction

$\bar{w}-\bar{z}=1.44$, standard deviation $z=1.29$, standard error $\bar{z}=0.39$,
standard deviation $w=2.19$, standard error $\bar{w}=0.45$

1 Project: $P=\Phi(1.44/2.0)=\Phi(0.55)=71\%$

10 Projects: $P=\Phi(1.44/1.0)=\Phi(1.44)=92\%$

20 Projects: $P=\Phi(1.44/0.82)=\Phi(1.76)=96\%$

Infinite Projects $=\Phi(1.44/0.59)=\Phi(2.43)=99\%$

APPENDIX D
PREDICTING PROJECT DEGREE OF INTERACTION AND PERFORMANCE

PREDICTING PROJECT DEGREE OF INTERACTION AND PERFORMANCE

Predicting Degree of Interaction (DOI):
Estimate your project's degree of interaction by filling in the table below. For each project phase, a weight factor (representing the relative value of interaction in that phase) is given (P_k). You can adjust the weight factors as you see fit, but the performance predictions below are based on these factors. Estimate the number of persons that will interact during each project phase (m_k). These persons **must** include at least one designer **and** one builder to be counted. Next, estimate the hours per month these people will spend in interaction for each project phase (t_{ik}). Fill in the number of months each project phase is expected to last (D_{ik}), then fill in the expected construction duration (CD). For each phase, the **DOI Score** = $\frac{P_k \times m_k \times t_{ik} \times D_{ik}}{160 \times CD}$ (160 is the approximate number of work hours per month). The final project DOI score is the sum of the DOI scores for each phase.

Project Phases	Weight Factor (P_k)	Number of Persons (m_k)	Interaction (hours/ month) (t_{ik})	Interaction Duration (months) (D_{ik})	Construction Duration (months) (CD)	DOI Score
Planning	0.16					
Conceptual Design	0.22					
Detailed Design	0.25					
Procurement	0.09					
Construction	0.22					
Start-Up	0.06					
Total Score	1.00					

Example for one phase

Detailed Design	0.25	12	16	5	18	0.083

Average Expected Project Performance (based on results of 38 completed projects):

If your project's predicted DOI score is *Less than 0.4*, your predicted:

- **Cost growth** is **6-12%** of estimated construction cost
- **Schedule growth** is **17-46%** of estimated construction duration
- **Number of modifications** is **6-11** times the estimated cost in millions
- **Modifications due to design deficiencies** are **18-41%** of predicted modifications
- **User satisfaction** is **5.9-7.8** on a scale of 1-10

Try adjusting your estimates in the table above to see what it takes to get a DOI score above 0.4.

If you project's predicted DOI score is *Greater than 0.4*, your predicted:

- **Cost growth** is **4-9%** of estimated construction cost
- **Schedule growth** is **3-21%** of estimated construction duration
- **Number of modifications** is **3-6** times the estimated cost in millions
- **Modifications due to design deficiencies** are **10-35%** of predicted modifications
- **User satisfaction** is **7.4-9.1** on a scale of 1-10

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VITA

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